1989

A trucking primer for the public works community.

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A TRUCKING PRIMER

for the

PUBLIC WORKS COMMUNITY

by

Robert R. Pete

A report submitted in partial fulfillment
of the requirements for the degree of

Master of Science in
Civil Engineering

University of Washington

1989

Approved by ______________________________

Program authorized
to offer degree ______________________________

Date ______________________________

University of Washington

ABSTRACT

A TRUCKING PRIMER FOR THE PUBLIC WORKS COMMUNITY

by Robert R. Pete

Chair of the Supervisory Committee: Professor J.P. Mahoney, Department of Civil Engineering

Those individuals who design, build and maintain our nation's highways understand how and why a pavement behaves as it does; however, they are often not overly informed about the characteristics of one of the largest users of highways.

This paper looks at one of the primary factors in pavement deterioration, trucks. It defines and explains several design parameters in truck construction and presents the design logic used with those parameters. A review of truck oriented legislation and an introduction to enforcement procedures as practiced by the Washington State Patrol is provided. Additionally, the results of a survey of northwestern truckers are presented.

Few conclusions are drawn in that the goal of this paper was to provide insight into the trucking industry. Opinions as to the future direction of both truck construction and legislation are included.

ACKNOWLEDGMENT

The author would like to express his gratitude to the many individuals, both in government and industry, who cheerfully answered questions and provided the information this report is based on. I also feel a great debt to Dr. Joe Mahoney, who provided support and direction numerous times.

My wife, Nancy was and is a constant help; she makes all of this worthwhile.

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INTRODUCTION

Many of our nations highways were and are designed using the American Association of State Highway and Transportation Officials (AASHTO) design equations developed in the early 1960's. In these equations, the controlling factor in the pavement thickness design is often the estimation of the truck traffic. The equations quantify, based on the data used to develop them, the deleterious effect this traffic will have. By determining the rate at which deterioration will occur, the design life of the pavement can be selected for a particular loading forecast.

The trucks in use today have undergone numerous changes since the design equations were developed. The intent of this paper is to provide an overview of trucks and tractor trailer operations. The decisions made in design and operation are driven by economic factors, (i.e., will this help to make a profit?). These decisions are strongly influenced, if not controlled, by the various regulations, taxes, fees and permits required by federal, state and local governments.

The people who devise these regulations, at the local, state and federal level, are competent, knowledgeable in their fields and have a clear understanding of what they want to accomplish. In some situations, however, the

decisions are made without a clear understanding of the fringe impacts implementation will have on the trucking industry as a whole. A form of 'technical tunnel vision' seems to come into play. In the eyes of the user, the preservation of the pavement seems to have become more importent than its use as a tool.

A difficulty for government administrators is that of communicating the decision making process to the public user. In a situation where a tax or restriction is imposed, a potentially irate user may be appeased by understanding the options which were considered and discarded. Conversely, government administrators, charged with maintaining the highways, may become upset with actions taken by a user (a trucking company) in response to regulation because they do not understand the thought process involved in reaching an operating decision.

That is the goal of this paper; to present to the reader the information necessary to understand, in a limited sense, the decision making process in the trucking industry. If the reader is left with a better awareness of how and why the industry operates the way it does, then this paper will have served its intended purpose.

Chapter I

Trucking Terminology

In attempting to discuss the trucking industry, it is necessary to first establish a base line of common terminology. This chapter will serve to define some of the various parts of trucks, trailers and combinations. While the terms used are generally accepted, the vocabulary is constantly changing and subject to local usage.

Tractors

A truck or truck tractor is composed of numerous component parts, manufactured by various companies and all assembled by the truck manufacturer to function as a single unit. Most tractors and commercial trucks are constructed in response to a specific order; they are not built to a standard plan and shipped to dealers for stocking and retail sale. As a result, they can be accurately described as customized, if not actually custom built. In practice, the manufacturer provides the prospective purchaser with a series of choices for various components of the tractor. The manufacturers representative will then help the purchaser select appropriate components.

These selections will be driven by the intended use of the truck. Such factors as the payload weight, annual

mileage, percent grade of the intended roads, road surface type, operating speed, area of operations, cargo characteristics and local law enter into the process (Fitch, 1984). A detailed discussion of the construction of trucks is not within the scope of this paper; however, discussion of several components which have a direct impact on pavement loadings follows.

The pavement designer is typically concerned with the number of axle loads the pavement will experience over the design life. The spacing between axles, the type, number and inflation pressure of tires and the type of suspension are not directly considered in the design process. The axle loads imposed on the pavement, converted into 18,000 pound Equivelent Single Axle Loads (ESALs), are the load input criteria used (AASHTO, 1986).

Some studies have been done which suggest that these other factors play a role, perhaps a significant one, in pavement performance. Refer to Appendix A for additional details.

Axles

Axles are commonly rated by the load they are able to carry; for example, an axle might be rated at 10,000, 15,000 or 20,000 pounds. The load limits on the axle are selected at the time of manufacture and are operational constraints; they can not safely be exceeded.

The front most axle is the steering axle; its function

is to control the direction of the vehicle in response to the drivers steering. The steering axle is normally as close to the front of the vehicle as design, wheel and tire size permit. This maximizes the total distance between the frontmost and rearmost axles on the truck, thus allowing the greatest load under the bridge formula (Refer to Chapter III).

If the steering axle is moved back, it is referred to as 'set back'. The purpose of moving the steering axle back is to increase the load applied to the front axle and to increase the maneuverability of the rig as a whole. Moving the axle back will decrease the turning radius of the tractor (Truck & Bus Industry Glossary, 1988).

The trailing axles on the tractor may be one of several kinds. At least one, and often two, will be "drive" axles. These transmit the motive force (generated by the engine and transmitted to the axle through the transmission) through the wheels and tires to the pavement. The number of drive axles will be determined at the time the tractor is built and will be dependent on the end use of the tractor (Fitch, 1984).

When the axle is a drive axle, it is often referred to as 'live'; if it is not powered, it is termed 'dead'.

On some tractors, only one axle in a tandem set may be driven (live). If the rear axle is powered, the rear axle is called a pusher axle. If the front axle of the tandem is live, the rear (dead) axle is called a tag axle.

Axles may be further designated as lift or flip axles. In this configuration, the axle will be either pinned and hinged so it can be 'flipped' up off the pavement when it is not needed, or it will be air actuated such that the axle can be lifted off the pavement when it is not needed. These axles will be down on the pavement only when required because of a load being hauled. This type of arrangement is useful when heavy loads are hauled in one direction and a lighter or no load is carried back (Truck & Bus Industry Glossary, 1988). By getting the additional axle, and tire rubber, off the road, the truck will run more economically. Tire wear will be decreased, fuel efficiency will be increased and overall operating costs will improve (Fitch, 1984).

Neither lift or flip axles are live axles; that is, the sole purpose of the axle is to transmit load to the pavement. These axles would be used in specific applications where a truck operator was attempting to comply with the weight distribution limits imposed by the bridge formula.

Axles are placed on the tractor either singly or in groups. A single axle is called a single axle, while a pair of axles is called a tandem; three axles in a group are called a tridem. The minimum spacing between the axles is governed by the size of tires planned for the wheels and the bridge formula. The maximum spacing will be driven by the strength of the frame, manuverability concerns, the bridge formula and legal limits.

Axles will still be considered tandem even if they are spread fairly far apart; although no hard and fast rule applies, the federal bridge formula treats axles under 8 feet separation as tandems for load limitations. Tandem axles usually have some type of load leveling or distribution system between the axles so neither axle can carry a disproportionate amount of the load ; this is usually incorporated into the suspension system by means of a leveling beam. As the two axles together are limited to a total load, and as each individual axle is limited to a lower individual load, the use of a leveling or distribution beam on tandem axle suspensions is universal (Pederson, 1989; Zieleg, 1989).

When the axles are spread farther than tire size requires, the arrangement is called a spread tandem. This set up would be used to comply with the bridge formula, which restricts loads based on the number of axles, the seperation of axles and the load . Figure 1 is an illustration of a spread tandem.

When discussing the drive system of a tractor or truck, it is common to hear phrases such as '4x4','6x4', etc. The numbers refer to the total number of wheel locations versus the number of drive wheel locations. Wheel location ignores the number of <u>tires</u>, single or dual used on the vehicle. Thus, a '6x4' simply means 3 axles (6 wheel locations) with 2 axles driven (4 wheel locations); a '4x2' would refer to a 2 axle truck with a single drive

axle. The recreational '4x4' is a two axle, all wheel drive truck (four wheel drive).

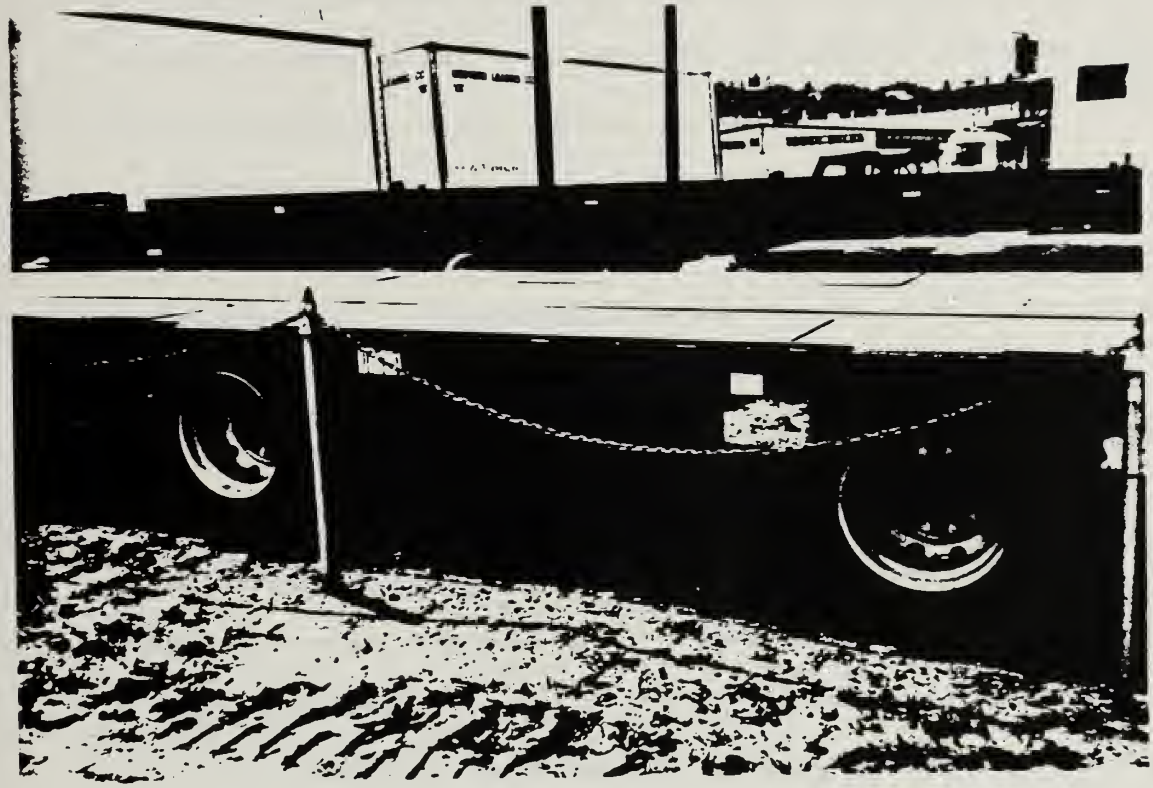


Figure 1. Spread Tandem

Suspensions

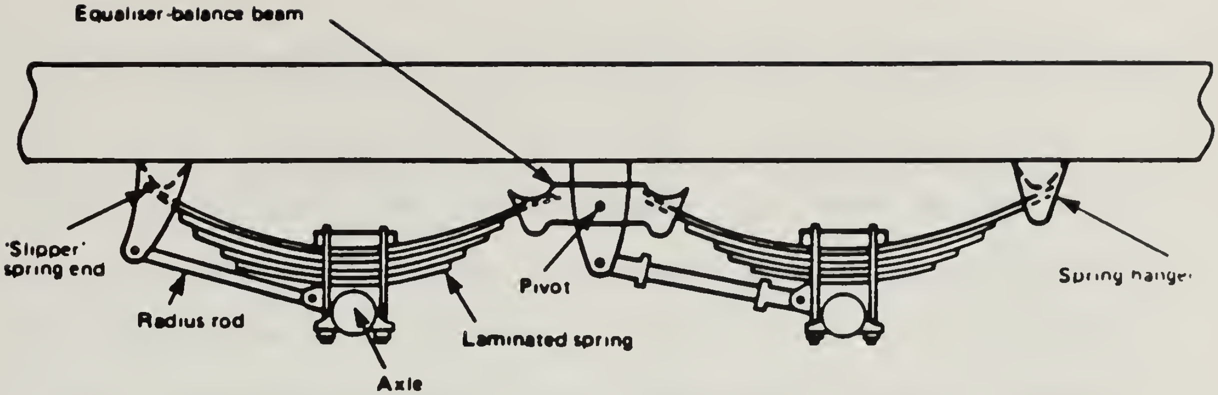
The purpose of the suspension is many fold. Among others, it must position and secure the axle to the frame, carry the load, provide resistance to side-sway and rollover, transfer driving and braking forces between the frame and the axles and provide suitable ride and cushioning properties. (Sternberg, 1976).

Depending on the axle location and the preference of the initial purchaser, several different suspensions may be employed. In general, three types of suspensions are in use on trucks today: the leaf spring, the walking beam and the air cushion; these are illustrated in Figure 2.

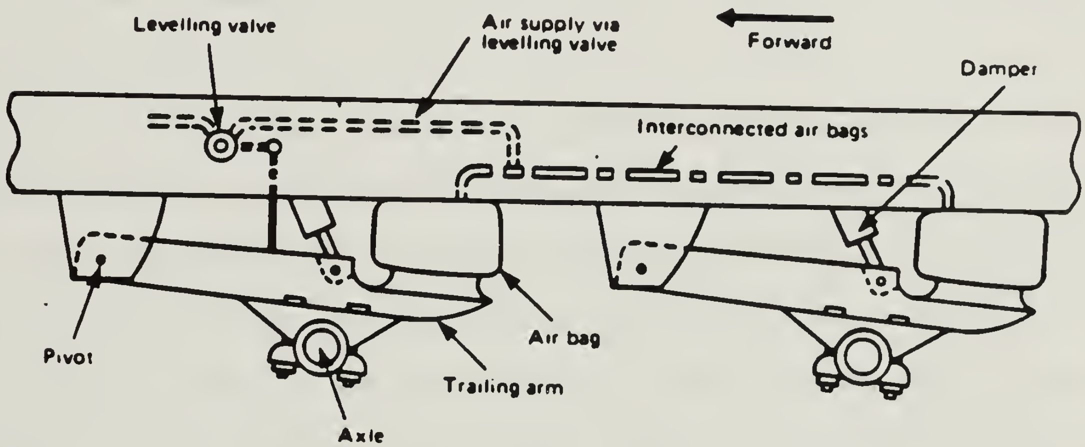
Each of these suspension types are available from several manufacturers; each manufacturer has made modifications to the suspension to individualize it. Although Figure 2 shows the basic form of these suspensions, one should be aware that numerous adaptations and permutations of these basic forms are in use today.

It should be noted that Figure 2 shows suspensions for tandem axles; each of these suspensions may also be constructed for single axle applications.

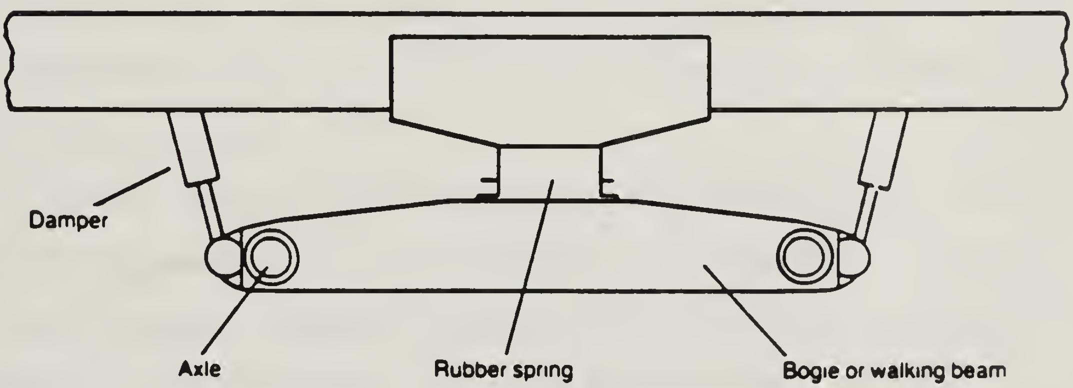
The front axle has a unique space constraint, as it is usually placed as far forward as possible to allow for the maximum spacing between axles to ensure compliance with the bridge formula. Ride characteristics and, to a lesser degree, load carrying capability are the concerns in selecting the suspension for this axle.



Leaf Spring



Air Cushion



Walking Beam

Figure 2. Three Types of Suspensions
Source: Mitchell and Gyenes, 1989.

The leaf spring is universally used on the steering axle. It is used almost by default; it has functioned so well for so long, and no new suspension (such as air cushion) has offered a clear improvement over leaf spring performance, that it appears it will remain the standard steer axle suspension for the foreseeable future (Ziebell, 1989).

The drive axles of a truck or tractor may have any of the three suspensions noted above. They are discussed more fully below.

The walking beam suspension functionally consists of a rigid frame connecting the axles to the frame. Rubber pads may be inserted into the frame to lessen the impact, but it provides minimal shock absorption. The full impact of dynamic loading is transmitted from the wheels to the frame of the truck. It is usually used in situations where loads are extreme and where the quality of the ride is not considered importent. Common applications are off road applications, concrete mixers, and logging, garbage and dump trucks (Fitch, 1984).

The leaf spring is similar to the suspension system used on automobiles; it is composed of individual "leaves" of steel, banded together to provide a spring of differential stiffness depending upon its deflection.

It has become common to taper the leaves to reduce weight; this also produces a more predictable spring rate. Since internal friction between the leaves is reduced, a

better, smoother ride is provided, both loaded and empty, with a tapered leaf spring (Fitch, 1984).

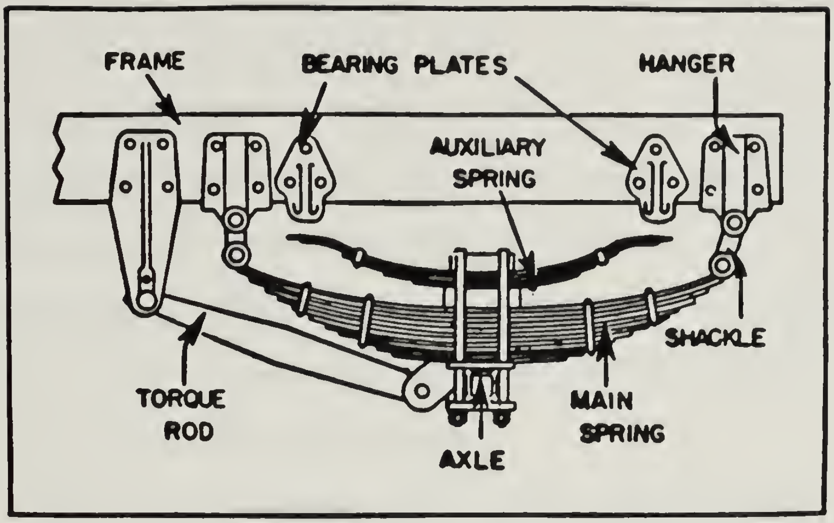
The number of leaves in the spring, the thickness of each individual leaf and the stiffness of the spring rate are all calibrated for the planned load.

In a single axle application, the springs are oriented at right angles to the axle and are attached to the axle at the midpoint of the spring.

Helper arms on leaf spring suspensions allow for a two-step response. In practice, they allow the unloaded (light) frame to be suspended on the relatively limber portion of the spring. When the truck is loaded, the load will be imposed on the stiffer portion of the spring, providing a more controlled ride. This spring configuration is shown in Figure 3.

In a tandem suspension the springs are oriented and are fastened to the ends of the axles in a similar manner to the single axle. The springs are "tied together", however, to provide for and allow load transfer between them. This ensures neither axle will end up carrying the total load alone. A common method is to employ a short steel beam, often called an 'equalizer' beam. This is illustrated in Figure 2.

Air suspensions are relatively new, first coming into use in the mid 1960's. The system provides rubber air cushions, or bladders which are inflated with air pressure provided from the air compressor on the tractor. The



Fiqure 3. Helper Spring Suspension

frame is typically attached to the axle by a trailing arm of structural steel to resist braking and acceleration forces. The sidesway and cushioning forces are supplied by the air bag (Fitch, 1984).

The system is heavier than a leaf spring system by about 100 pounds on tandem drive axles, and by about 300 pounds per dead axle on a trailer or semitrailer (Pederson, 1989; Ziebell, 1989). As a result, the truck will have a reduced payload capacity when compared to a leaf spring equiped truck.

Studies indicate that these suspensions produce different dynamic loads on pavements. Additional research is being done in this area to quantify and clarify the issue. Refer to Appendix B for details.

Tires

In selecting tires for a tractor, the operator faces many of the same concerns individual automobile owners face. Desirable traits will include a fuel efficient design, a high mileage rating, good handling on the road with dependable traction and certainly a comfortable ride. Additionally, a strong tire that will not prematurely puncture or wear from road hazards is important.

A separate concern that a trucker has is the number of tires to put on each axle. This will in some cases be governed by the loads to be carried on a given axle; it may be governed by safety considerations, by economic cal-

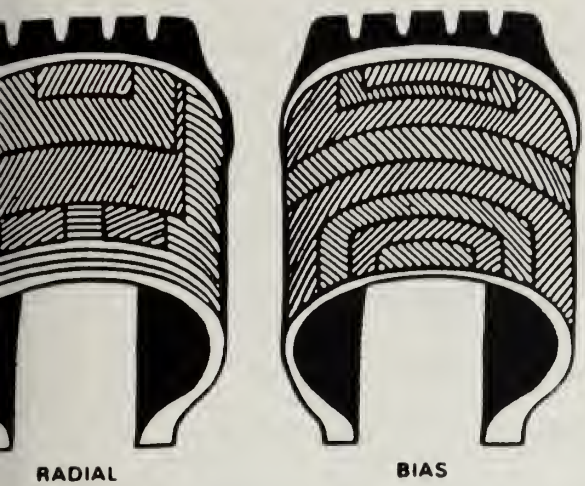
culations or (most likely) by some combination of all of these (Fitch, 1984; Ford and Charles, 1988).

A tire will be rated for a specific load carrying capacity at a particular inflation pressure at a given speed. Accordingly, the operator will select tires based on the intended load and speed, but the physical size of the tire must also be considered. A tire may satisfy all the performance criteria, but be too large to fit under the frame and within the suspension of a particular truck (Michelin, 1988).

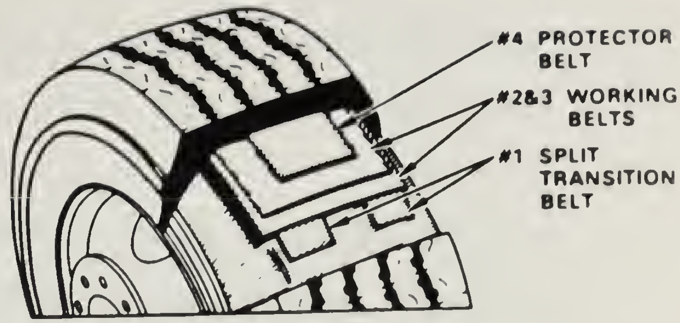
Truck tires available today include bias belted tires, radial tires, low profile radials and the super-single radial tire. Each of these tires may be purchased with a plethora of tread types.

Finally, each of these tires may be recapped, meaning that additional rubber with new tread may be added to the tire once it has reached the limit of its original tread life. Thus a tire, with recapping, may be used several times over its original rated mileage. Recapping a tire is much less expensive than purchasing new tires; a recap costs about one third of a new tire (Michelin, 1988).

The bias ply or cross belted tire refers to a tire which is constructed by wrapping plies or belts diagonally, crisscrossing each other as shown in Figure 4. The number of plies required in a bias ply tire to carry a particular load results in a fairly stiff sidewall. This adversely affects the tires ability to perform, both in on



Radial v. Bias Construction



Typical Radial Construction

Radial Tire Cross- Section

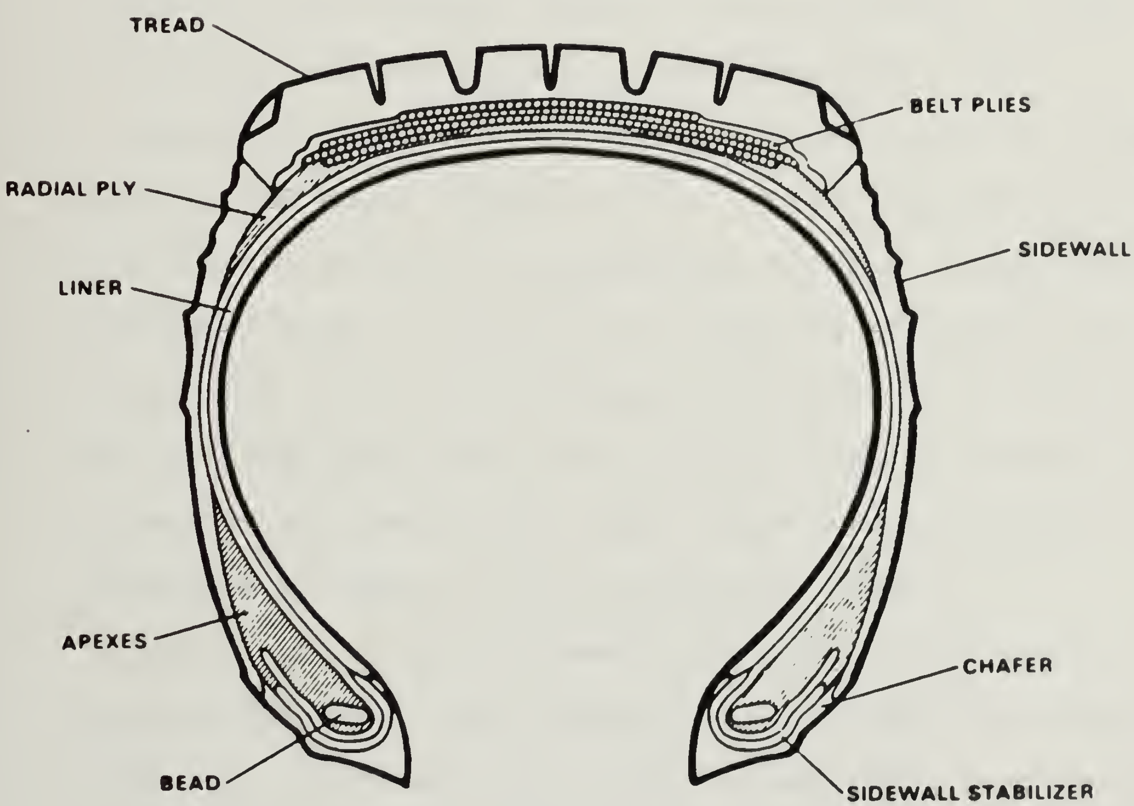


Figure 4. Radial and Bias Belted Tire Construction
Source: Ford and Charles, 1988.

road traction and tread life.

In a radial tire, the plies are laid radially; this results in a more flexible sidewall, which provides improved performance and durability (Ford and Charles, 1988; Michelin, 1988).

A low profile radial, commonly abbreviated LP, is simply a smaller diameter tire with the equivalent load capacity of a larger tire. As a general rule, LP tires are lighter than full size tires.

As trucks are restricted by weight, heavier tires detract from the pay load they can carry. Accordingly, LP radials allow a higher payload while providing the benefits of radials (Michelin, 1988; Pederson, 1989).

An additional tire currently available, but not widely used is the super single radial. As may be gathered from its name, this tire is designed to replace a dual tire arrangement,with a single tire. The tire is usually narrower than a set of equivelent dual tires, about 70 percent of the dual width, and has an inflation pressure of about 120 psi versus non super single radial inflation pressures of about 100 psi (Michelin, 1988).

In a dual tire arrangement, when (or if) a flat tire occurs the remaining tire of the dual set is capable of carrying the load for a short time. The truck can be driven to a truck service center and the flat tire replaced or repaired. Minimal time is lost, and the driver can resolve the problem with no additional help or expense

other than the actual tire repair cost.

A single tire, such as a super single, will halt a truck if it deflates. No additional tire is available to allow the truck to 'limp' in for repairs. Because of the larger size of the super single compared to a regular tire, it is difficult for a single person to change. A tow or repair truck is usually required and must be dispatched. Any economy which is realized from operational savings may be quickly lost (Federson, 1989; Ziebell, 1989).

In deciding on tires, the trucker will first look to the steering axle. Single tires are used due to the light (usually 12,000 pounds) loads imposed on this axle and because of handling characteristics (Michelin, 1988; Ziebell, 1989).

Because a flat tire on this axle would cause severe steering and safety problems, only new tires (as opposed to recapped tires) are used as an industry norm (Michelin, 1988; Federson 1989; Ziebell, 1989).

Table 1 is an example of a tire selection table for a 22.5 inch diameter rim. (This table is a partial listing of MICHELIN brand radial truck tires). Some basic tread patterns for these tires are shown in Appendix C.

As an example of tire selection, if plans call for a maximum speed of 65 mph with a load on the front axle not to exceed 12,000 pounds, all of the tires available from this table <u>may</u> satisfy this performance criteria.

Table 1. Tire Selection Table

Source: Michelin, 1988.

Tire Specifications for Wheel Diameter: 22.5

LOADS PER AXLE (lbs. and kg.) AT DIFFERENT PRESSURES — 2 TIRES: SINGLE (S) 4 TIRES: DUAL (D)

SIZE	Tread	Load Range	Loaded Radius in.	Loaded Radius mm	Overall Diameter in.	Overall Diameter mm	Overall Width in.	Overall Width mm	Approved Rims width	Approved Rims cont.	Min. Dual Spacing in.	Min. Dual Spacing mm	Approved Flaps	App. Tubes	Revs Per Mile	Tread Depth 32nds		psi	65	70	75	80	85	90	95	100	105	110	115			MAX
																		kPa	450	480	520	550	590	620	660	690	720	760	790			SPEED
275/80R22.5	PXZA	LRH 146/144	18.6	473	40.2	1022	11.3	288	8.25	—	12.5	318	—	Tbls.	518	16	lbs.	S	8,310	8,870	9,430	9,990	10,530	11,070	11,610	12,150	12,680	13,220	13,880			65 MPH
																		D	14,720	15,680	16,670	17,700	18,700	19,720	20,700	21,650	22,600	23,530	24,700			
							11.0	278	7.50	—	12.2	310					kg.	S	3,770	4,020	4,280	4,530	4,770	5,020	5,270	5,520	5,760	6,000	6,300			105 kph
																		D	6,680	7,110	7,560	8,030	8,480	8,940	9,390	9,820	10,250	10,670	11,200			

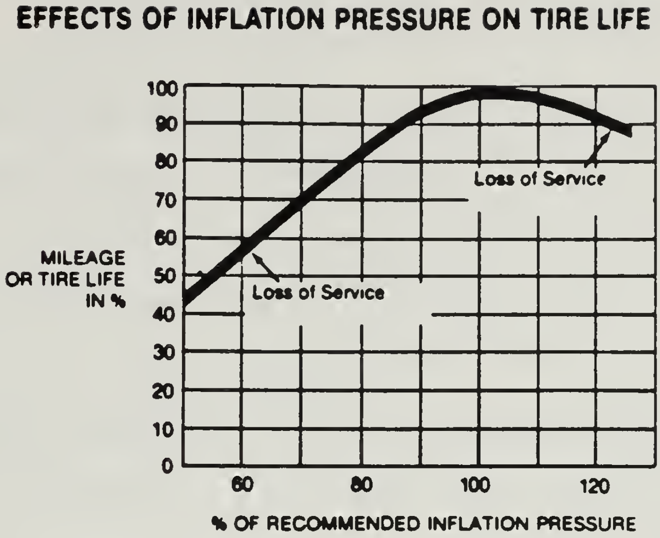
SIZE	Tread	Load Range	Loaded Radius in.	Loaded Radius mm	Overall Diameter in.	Overall Diameter mm	Overall Width in.	Overall Width mm	Approved Rims width	Approved Rims cont.	Min. Dual Spacing in.	Min. Dual Spacing mm	Approved Flaps	App. Tubes	Revs Per Mile	Tread Depth 32nds		psi	70	75	80	85	90	95	100	105	110	115	120	125	130	MAX
																		kPa	480	520	550	590	620	660	690	720	760	790	830	860	900	SPEED
295/80R22.5	PXZA	LRH 150/146	19.3	490	41.5	1054	11.7	298	8.25	—	13.0	331	—	Tbls.	501	16	lbs.	S	9,410	9,990	10,570	11,140	11,740	12,310	12,900	13,480	14,050	14,770				65 MPH
																		D	16,840	17,860	18,960	20,030	21,120	22,180	23,220	24,220	25,220	26,440				
							12.0	305	9.00	—	13.3	338					kg.	S	4,270	4,530	4,790	5,050	5,330	5,580	5,850	6,110	6,380	6,700				105 kph
																		D	7,640	8,100	8,600	9,080	9,580	10,070	10,530	10,980	11,440	11,980				
315/80R22.5	PXZA	LRJ 154/149	19.3	490	42.4	1077	12.4	316	9.00	—	13.8	351	—	Tbls.	490	18	lbs.	S	10,800	11,430	12,090	12,810	13,360	13,990	14,620	15,200	15,900	16,540				65 MPH
																		D	18,700	19,800	20,900	22,000	23,120	24,220	25,320	26,420	27,540	28,640				
																	kg.	S	4,900	5,180	5,480	5,810	6,060	6,350	6,630	6,920	7,210	7,500				105 kph
																		D	8,480	8,980	9,480	9,980	10,480	10,990	11,490	11,980	12,480	12,980				
315/80R22.5	PXZY	LRJ 154/149	19.6	498	42.4	1078	12.5	317	9.00	—	13.8	351	—	Tbls.	490	18	lbs.	S	10,800	11,430	12,090	12,810	13,360	13,990	14,620	15,200	15,900	16,540				65 MPH
																		D	18,700	19,800	20,900	22,000	23,120	24,220	25,320	26,420	27,540	28,640				
																	kg.	S	4,900	5,180	5,480	5,810	6,060	6,350	6,630	6,920	7,210	7,500				105 kph
																		D	8,480	8,980	9,480	9,980	10,480	10,990	11,490	11,980	12,480	12,980				
315/80R22.5	PXZY	LRL 154/149	19.6	498	42.4	1078	13.0	317	9.00	—	13.9	352	—	Tbls.	490	18	lbs.	S					13,360	13,990	14,620	15,200	15,900	16,540	16,970	17,500	18,000	65 MPH
																		D					23,120	24,220	25,320	26,420	27,540	28,640	30,240	31,570	33,020	
																	kg	S					6,060	6,350	6,630	6,920	7,210	7,500	7,700	7,940	8,160	90 kph
																		D					10,480	10,990	11,490	11,980	12,480	12,980	13,720	14,320	14,980	
385/65R22.5	XZY	LRJ 158	19.6	498	42.3	1074	14.9	378	11.75	—	—	—	—	Tbls.	491	21	lbs.	S		12,620	13,280	13,890	14,500	15,100	15,700	16,440	17,080	18,000	18,300	18,740		65 MPH
																		D														
							15.1	383	12.25	—	—	—					kg	S		5,720	6,020	6,300	6,580	6,860	7,180	7,480	7,740	8,180	8,300	8,500		105 kph
																		D														
425/65R22.5	XZY	LRL 160	20.5	520	44.5	1130	16.5	420	13.00	—	—	—	—	Tbls.	469	21	lbs.	S		15,100	16,000	16,800	17,680	18,440	19,180	20,000	21,000	21,480	22,220	22,800		65 MPH
																		D														
							16.2	412	12.25	—	—	—					kg	S		6,860	7,260	7,620	8,020	8,360	8,700	9,070	9,530	9,740	10,080	10,340		105 kph
																		D														

Notice the overall diameter ranges from 40.2 inches up to 44.5 inches. These dimensions would be checked against the clearances available on the chassis where the tires will be installed. While perhaps obvious, the tire must be free to rotate at all times; a large tire may rub against suspension components, the underpart of the body, against steering rods or against a dual tire in a tight turn or when going over a bump. Enough space must also be allowed for cooling of the tire to occur while it is in operation (Michelin, 1988).

An inflation pressure must also be selected. In this particular case, available pressures for a 12,000 pound axle load at 65 mph range from 70 psi to 100 psi depending on the tire selected (Table 1).

Note, however, that by increasing the tire inflation pressure on any particular tire the rated load may be increased. Higher pressures should only be used if the higher load is actually applied, however; Figure 5 illustrates the effect of inflation pressure on tire life. Both over inflation and under inflation have an impact on service life; tire inflation pressures should be adjusted according to the actual load being carried (Michelin, 1988; Ford and Charles, 1988).

The initial cost, tire weight, performance considerations and manufacturers warranty would all be considered by a trucker before purchasing tires. Tires range in price from about $240 for an LP trailer tire to as much as



% Rated Inflation	% Expected Mileage
110	105
100	100
90	95
80	84
70	67
60	43

Figure 5. Inflation Pressure Effects
Source: Ford and Charles, 1988.

$500 for a super single, with drive tires being, in general, more expensive than others. Fleet owners will attempt to standardize as much as possible the inventory they must carry (Fitch, 1984).

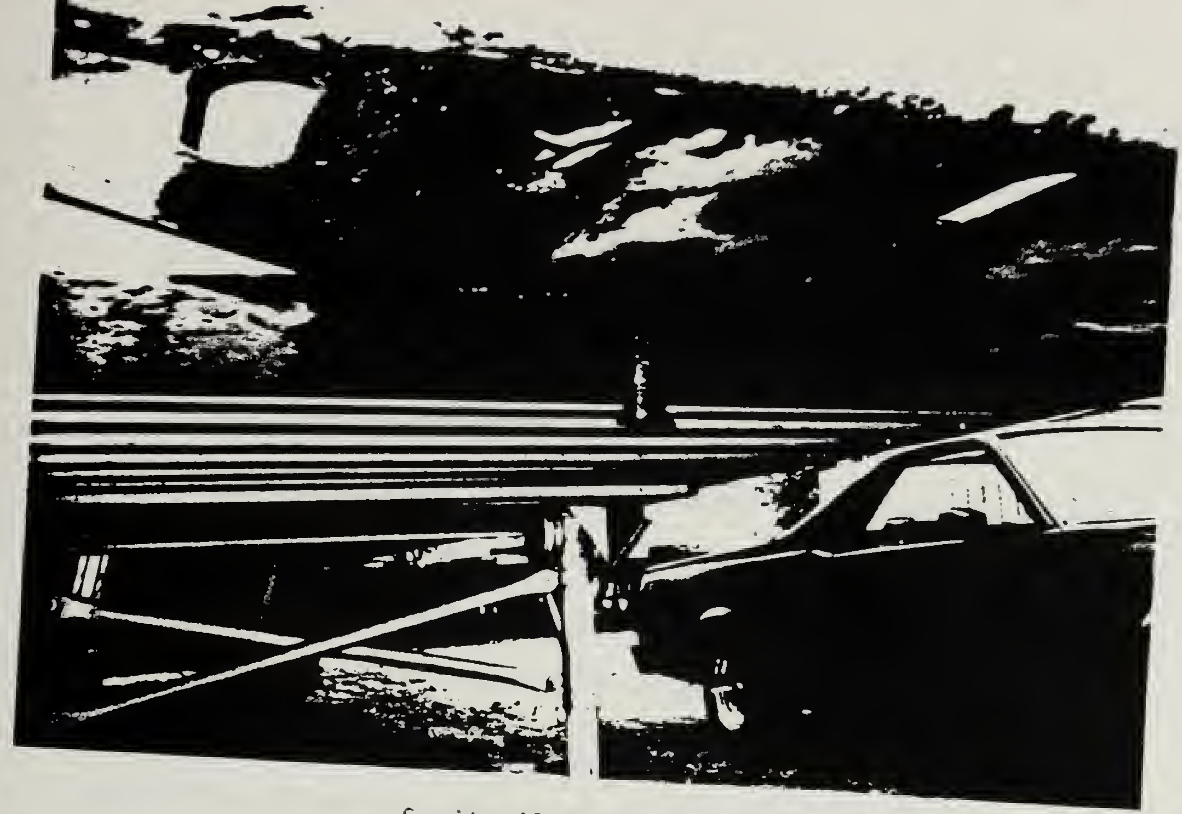
On the non-steer axles, (the drive and/or dead axles), an identical process is followed with the exception that dual tires may be used on the axle. A review of Table 1 indicates that, at a given inflation pressure, dual tires almost double the load capacity allowed.

The reason the load is not exactly twice the single tire rating is based on the unequal loading the two tires will receive due to the crown in the road. The crown will impart a slight tilt to the truck; as a result, the weight of the truck will be unequally distributed between the ends of the axle and also between the tires. The lower limit on the dual tires may be thought of as a safety factor to prevent overloading of an individual tire (Ford and Charles, 1988).

Miscellaneous Terms

The tractor exists as a means to haul around a trailer or semitrailer; these hook up to the tractor by means of several different pieces of specialized equipment.

On the rear of the tractor, located above the drive axle(s), is the 'fifth wheel', shown in Figure 6.



Semitrailer Kingpin

Figure 6. Fifth Wheel

It is not a wheel in the round rolling sense, but a:

> "...plate type device, carried by the tractor with jaws which lock onto a pin mounted on a trailer so the trailer can be towed by the tractor..." (Truck & Bus

Industry Glossary,1988).

The fifth wheel functions both as a bearing plate for a semitrailer to transfer load to the tractor and as a coupling device to tow the semitrailer.

Additionally, the fifth wheel, although locked in place during operations, may be slid forward or backward on its mounting tracks. By moving the fifth wheel forward or backward, the load from the semitrailer passed to the tractor axles, in particular the steering axle, may be changed. Moving the fifth wheel back will lighten the front axle load (and increase the drive axle load), while moving it forward will increase the front axle load (Pederson, 1989).

If an operator was in a situation where the drive axle(s) were overloaded, by moving the fifth wheel forward some of the load would be transferred to the steering axle. Conversely, if steering became difficult because of too much load on the steering axle, or if weigh scales showed the front axle overloaded, the fifth wheel could be moved to redistribute the load without physically moving or repacking the actual cargo itself.

Trailer connections will be discussed under trailers.

The cab of a tractor or truck has two basic options, conventional and cab over engine (COE). While each design has advantages, the COE allows a greater percentage of overall length to be devoted to payload than conventional design. As overall length is a restricted dimension on some state highways, this may translate directly into additional capacity (Fitch, 1985). These cab variations are illustrated in Figure 7.

<u>Trailers</u>

Trailers may be grouped into two major categories; semitrailers and "true" trailers. As discussed, semitrailers have no axle in the front portion of their length; they depend on something else to support them. When hooked to a tractor, this is the fifth wheel. When a semitrailer is unhooked, a set of drop down supports, called landing gear, are used.

Trailers have an axle, or axles, located at each end and are self supporting. They are generally hooked up to the truck or tractor by means of a tow or pull bar which fastens to a pintle hook. Figure 8 is an example of a trailer hookup.

Cab Over Engine v. Conventional

Source: MVMA, 1984.

Cab Over Engine
Source: Fitch, 1984.

Conventional
Source: Fitch, 1984.

Figure 7. Cab Variations

Figure 8. Trailer Connection Point

Axles

Although similar in most respects to tractor axles, trailer axles are not powered. They function strictly as load carriers. Accordingly, the number and location of axles is strictly a function of projected load and complying with regulations such as the bridge formula.

Trailer axles may, however be either fixed or steering axles. A steering axle in this case does not mean actively steered by the driver. The basic difference is whether the tires and wheels are free to move in a direction other than parallel to the direction of travel (i.e. to 'turn'). These are most useful in long combinations and are discussed in more detail under "trains".

Tires

A similar process to tractor or truck tire selection occurs with trailer selection. The tread pattern is usually different from that selected for the steering or drive axles, and recapped tires will often be used (Pederson, 1989). The rating of the tire for load, speed and inflation pressure is the same.

An additional benefit of LP radials so far as trailer applications are concerned is their smaller diameter. Truck trailers are subject to a physical limitation on their height. In addition to stability/safety concerns, the vehicle must be able to physically fit under bridges, lights, signs or other overhead obstructions on the haul

route. By lowering the vehicle, the LP tire allows a taller trailer with additional capacity, but the same absolute height.

Suspensions

The suspensions used on trailers are the same types (walking beam, leaf spring and air cushion) which trucks and tractors use. They are sized for a particular axle load rating, but function in the same manner as on tractors discussed above.

Industry sources (Pederson, 1989; Kantor,1989) disagree on the most common suspension type. In general, the author feels that the leaf spring is the most common for over-the-road applications, while the walking beam is most common for off road or mixed applications. Air cushion suspension use is increasing, but will take a while to capture a sizable market segment due to the longevity of existing equipment (Sullivan, 1988; Ziebell, 1989).

The suspension used on the trailer need not be the same as that used on the tractor. For example, a tractor with an air suspension may pull a trailer with a walking beam suspension. The motion of the trailer, however will have a large influence on the quality of the ride of the tractor (Pederson, 1989; Ziebell, 1989).

Miscellaneous Terms

In hooking a semitrailer to a tractor, a pin attached to the semitrailer protrudes down through the jaws on the fifth wheel, which grasp and hold it. This pin is called the kingpin. The purpose of the kingpin is to transfer horizontal force; the vertical support of the trailer load is provided by the bearing plate of the fifth wheel (Truck & Bus Industry Glossary, 1988).

Operating Configurations

Figure 9 differentiates between a truck, a tractor - semitrailer and a tractor-trailer.

A truck is a single unit, combining both powerplant and payload capability within the same frame. A tractor is simply a power plant with no intrinsic payload capability; it must be hooked up to a trailer or semitrailer in order to haul goods.

The semitrailer has no axles up front, and normally one, two (tandem) or three (tridem) axles in the back. The semitrailer is hooked to the tractor by means of a fifth wheel and kingpin; it is designed so that a substantial part of its own weight and of its load rests on the other vehicle.

A trailer is freestanding and has axles at each end of its length. It is designed and constructed so that all of its load rests upon its own wheels. The trailer is attached to the tractor by means of a drawbar.

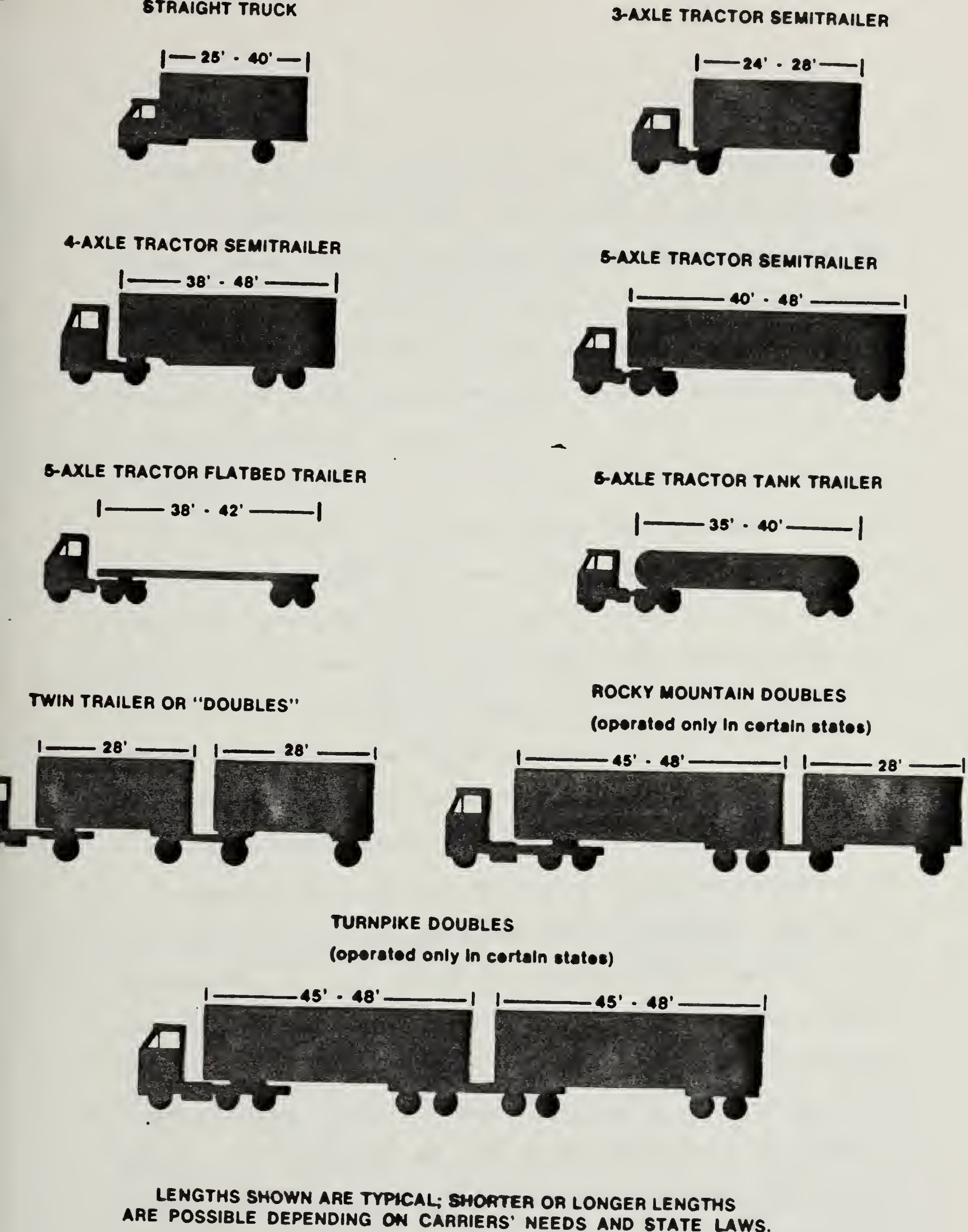


Figure 9. Truck Configuration Types
Source: American Trucking Association, 1989.

The twin trailer, or 'doubles', is a tractor unit pulling a semitrailer and a full trailer coupled together.

Both Rocky Mountain doubles and turnpike doubles are characterized by tractors pulling full semitrailers, but in turnpike doubles the trailing component is a full size trailer, while the Rocky Mountain double is brought up by a shorter (28 foot) trailer.

Trains

In some cases, two semitrailers may be hauled by one tractor (as opposed to a semitrailer and a trailer). The resulting combination is called a "train". The type of connection between the two semitrailers determines what type of train (A train, B train or C train) will result; Figure 10 illustrates these trains.

A semitrailer must be mounted on a fifth wheel, but the fifth wheel does not have to be on the tractor.

A semitrailer may be mounted on a converter-dolly so that it will function as a trailer. A converter-dolly is essentially a fifth wheel on wheels, with a means of attaching to the vehicle in front. Depending on the type of dolly, the resulting combination will have differing capabilities. For example, a dolly may have fixed wheels, the wheels may be free to turn (a steering dolly), and the dolly may be attached to the lead vehicle by means of either a single or double drawbar. Figure 11 illustrates these properties.

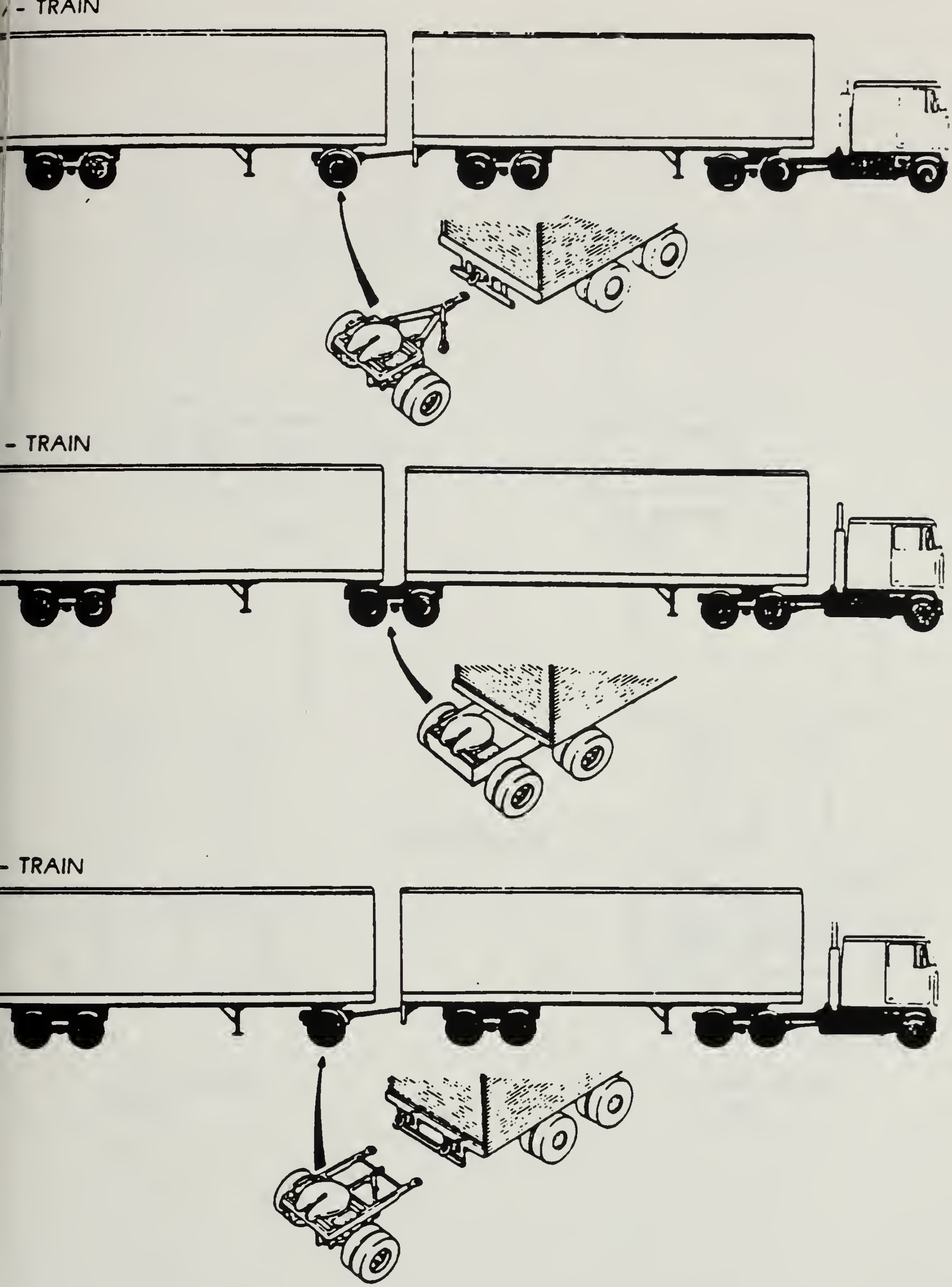


Figure 10. Train Types
Source: Woodrooffe, LeBlanc and El-Gindy, 1989.

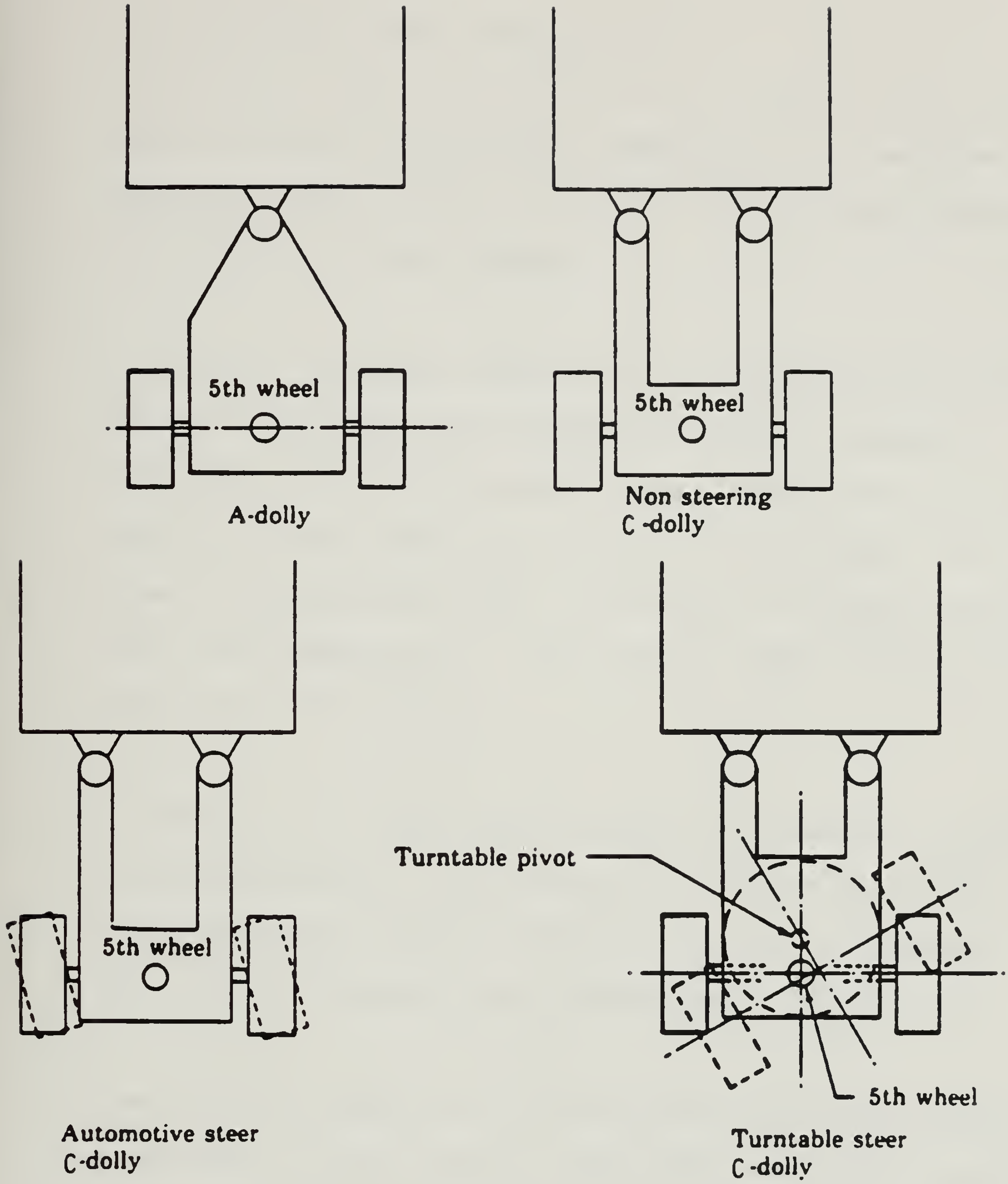


Figure 11. A-Dolly and C-Dolly Options
Source: Woodrooffe, LeBlanc and El-Gindy, 1989.

Trains have been defined as:

A-Train: An A-Train is a tractor pulling two semitrailers; the trailing semitrailer is mounted on a converter-dolly which is attached to the lead semitrailer by means of a single drawbar.

B-Train: A B-Train consists of a tractor pulling two semitrailers: the lead semitrailer has an extended sub-frame. On this extended frame, which sticks out behind the semitrailer, is mounted a fifth wheel. The fifth wheel is supported by the rear axle of a spread tandem on the first semitrailer. The trailing semitrailer mounts onto this fifth wheel.

C-Train: A C-Train also consists of a tractor pulling two semitrailers. It is similar to an A-Train except the converter-dolly has two drawbars; this eliminates one point of articulation from the ensuing combination.

The differing aspect is the means of hooking the second semitrailer to the first. Each train has significantly different handling characteristics. While each group has advocates, Canada has recently enacted legislation to encourage the use of B-trains. This legislation appears to be driven by safety and handling concerns (Nix, 1988).

Chapter II

The Trucking Industry

COMPOSITION

Trucks, tractors and trailers are a complex mix of equipment. The word truck itself can be accurately applied to everything from a light imported pickup truck to a concrete mixer to a massive transporter for the space shuttle. In order to differentiate between them, trucks have been divided into classes by gross vehicle weight (this rating system was developed by vehicle manufacturers in the 1940s). Gross vehicle weight is the weight specified by the manufacturer as the maximum loaded weight (truck plus cargo) of a vehicle. Tare weight, sometimes called curb weight, is the weight of a truck exclusive of a payload (Truck & Bus Industry Glossary, 1988).

These classes are:

CLASS	GROSS VEHICLE WEIGHT (lb)
1	6,000 or less
2	6,001 - 10,000
3	10,001 - 14,000
4	14,001 - 16,000
5	16,001 - 19,500
6	19,501 - 26,000
7	26,001 - 33,000
8	33,001 or more

The Motor Vehicle Manufacturers Association (MVMA) is a trade association formed to improve the design, manufacture and use of motor vehicles. It is composed of most of the major American truck manufacturers: Chrysler, Ford, General Motors, Honda of America, Navistar International, PACCAR Inc. and Volvo North America. They have grouped vehicles into classes by weight (MVMA, 1984). These classes are:

Light Trucks : Classes 1,2 and 3 (under 14,000 lbs.)

Medium Trucks: Classes 4,5,6 and 7 (14,001 to 33,000 lbs.)

Heavy Trucks : Class 8 (over 33,001 lbs.)

A rough breakdown of registrations shows that about 90 percent of all truck registrations are light, 6 percent are classified medium and 4 percent are classified heavy (with a total weight over 33,001 pounds) (Building the Tools, 1983; American Trucking Trends, 1989). Light trucks include pickups, vans and panel trucks.

The majority of heavy trucks are in fleets owned and operated by companies rather than individual owner-operators. Data collected by the American Trucking Association (American Trucking Trends, 1989) indicates that, in 1987, 1.4 million tractors and 3.5 million commercial trailers were registered; 100,000 to 150,000 owner-operators were registered.

As most owner-operators have a single rig, this would

indicate over 90 percent of the operating combinations are fleet owned.

Truck transportation is normally classified as either private or for-hire. Private carriers are those companies who use their own vehicles, either owned or leased, to move their own goods. The principle business of the corperation is not transportation. Examples of private fleets would be those owned by a department store, a bakery or a dairy.

A for-hire carrier is paid to move freight for someone else. For-hires are further classified either interstate, intrastate or local. Intrastate and local firms are regulated by local (state, county and/or city) authority, while interstate traffic is controlled by the Interstate Commerce Commision (ICC). The ICC further breaks down interstate trucking into common carriers, contract carriers and exempt carriers.

A common carrier is available to the general public to carry freight at a published rate between any points which the firm has the authority (granted by the ICC) to serve.

A contract carrier generally operates only under contract to one or a limited number of customers on a long term basis. Contract carriers must be permitted by the ICC.

Exempt carriers are in specific operations used for transporting particular items listed by law, such as agricultural commodities, newspapers, etc. and trucks used in

certain other limited fashion.

An independent trucker is simply a trucker who does not hold a certificate or operating permit from the ICC (Fitch, 1984).

Prior to 1980, interstate trucking was a highly regulated business, with routes and rates set by the ICC. The Motor Carrier Act of 1980, however deregulated the trucking business with much the same result which de-regulation had on the airlines.

Revenues and Taxation

The industry as a whole earned about $225 billion in 1987, representing 77 percent of the nations freight bill and 5 percent of the Gross National Product (ATA, 1989). The American Trucking Association estimates the relative share of the shipping market held by various modes; expressed in terms of revenue, trucks held 75 percent. The MVMA estimates the truck share, based on ton-miles, at 25 percent. In either case, the transport role played is a significant one.

Taxes are collected by federal, state and local governments. Appendix C contains tax charts illustrative of taxes incured by various vehicles. On average, a 5 axle truck-semitrailer paid $4,084 (state) + $4,241 (federal) = $8,325 in taxes to operate in 1987 (ATA, 1989). The amount of taxes paid is dependent upon the fuel type (gas versus diesel), the gross weight of the truck combination and the

total number of axles. These are all components which the initial purchaser of the vehicle may specify.

This information illustrates the size and complexity of the industry and the dollar value of commerce which is involved. It is a large, complicated and sophisticated industry.

The MVMA tracks trends in the industry. Some of the more interesting are presented here :

- The van has been the most popular trailer body type for the past five years, by a factor of about 8:1.

-Flat beds are second, followed by dump trucks, then tankers.

-Since 1977, the share of the transport market captured by trucking has hovered around the 25 percent mark. In 1987, 24.92 percent equated to 661 billion ton-miles of freight.

-In 1988, the balance in the highway trust fund, funded with user fees, totaled over fourteen billion dollars. The fund has been increasing in value for the past six years.

Chapter III

The Bridge Formula

When regulators initially began to restrict the loads which a truck could place on a road, they looked to what they considered the weak link: bridges. The concept of spreading the load by control of axle spacing was adopted with the intent of preventing overloading of the structural components of bridges. The results were codified in the bridge formula (FHWA, 1984).

The bridge formula is an equation which restricts the loads which may be placed on an axle or group of axles. The equation is:

$$W=500 * (LN/(N - 1) + 12N + 36)$$

Where:

W is the maximum weight (in pounds) which can be carried on any group of two or more axles, computed to the nearest 500 pounds

L is the distance in feet between the <u>extremes</u> of any group of two or more consecutive axles

N is the number of axles in the group under consideration (FHWA, 1984).

Table 2 is a tabulation of allowable loads computed by the bridge formula. Note the increasing loads both with increasing number of axles and/or increasing separation.

Source: Federal Highway Administration, 1984.

[Bridge table B]

Tandem Axle Weight

Distance in feet between the extremes of any group of 2 or more consecutive axles	Maximum load in pounds carried on any group of 2 or more consecutive axles [1]							
	2 axles	3 axles	4 axles	5 axles	6 axles	7 axles	8 axles	9 axles
4	34,000							
5	34,000							
6	34,000							
7	34,000							
8 and less	34,000	34,000						
More than 8	38,000	42,000						
9	39,000	42,500						
10	40,000	43,500						
11		44,000						
12		45,000	50,000					
13		45,500	50,500					
14		46,500	51,500					
15		47,000	52,000					
16		48,000	52,500	58,000				
17		48,500	53,500	58,500				
18		49,500	54,000	59,000				
19		50,000	54,500	60,000				
20		51,000	55,500	60,500	66,000			
21		51,500	56,000	61,000	66,500			
22		52,500	56,500	61,500	67,000			
23		53,000	57,500	62,500	68,000			
24		54,000	58,000	63,000	68,500	74,000		
25		54,500	58,500	63,500	69,000	74,500		
26		55,500	59,500	64,000	69,500	75,000		
27		56,000	60,000	65,000	70,000	75,500		
28		57,000	60,500	65,500	71,000	76,500	82,000	
29		57,500	61,500	66,000	71,500	77,000	82,500	
30		58,500	62,000	66,500	72,000	77,500	83,000	
31		59,000	62,500	67,500	72,500	78,000	83,500	
32		60,000	63,500	68,000	73,000	78,500	84,500	90,000
33			64,000	68,500	74,000	79,000	85,000	90,500
34			64,500	69,000	74,500	80,000	85,500	91,000
35			65,500	70,000	75,000	80,500	86,000	91,500
36		Exception	66,000	70,500	75,500	81,000	86,500	92,000
37			66,500	71,000	76,000	81,500	87,000	93,000
38			67,500	71,500	77,000	82,000	87,500	93,500
39			68,000	72,500	77,500	82,500	88,500	94,000
40			68,500	73,000	78,000	83,500	89,000	94,500
41			69,500	73,500	78,500	84,000	89,500	95,000
42			70,000	74,000	79,000	84,500	90,000	95,500
43			70,500	75,000	80,000	85,000	90,500	96,000
44			71,500	75,500	80,500	85,500	91,000	96,500
45			72,000	76,000	81,000	86,000	91,500	97,500
46			72,500	76,500	81,500	87,000	92,500	98,000
47			73,500	77,500	82,000	87,500	93,000	98,500
48			74,000	78,000	83,000	88,000	93,500	99,000
49			74,500	78,500	83,500	88,500	94,000	99,500
50			75,500	79,000	84,000	89,000	94,500	100,000
51			76,000	80,000	84,500	89,500	95,000	100,500
52			76,500	80,500	85,000	90,500	95,500	101,000
53			77,500	81,000	86,000	91,000	96,500	102,000
54			78,000	81,500	86,500	91,500	97,000	102,500
55			78,500	82,500	87,000	92,000	97,500	103,000
56		Interstate Gross	79,500	83,000	87,500	92,500	98,000	103,500
57		Weight Limit	80,000	83,500	88,000	93,000	98,500	104,000
58				84,000	89,000	94,000	99,000	104,500
59				85,000	89,500	94,500	99,500	105,000
60				85,500	90,000	95,000	100,500	105,500

[1] The permissible loads are computed to the nearest 500 pounds. The modification consists in limiting the maximum load on any single axle to 20,000 pounds.

[2] The following loaded vehicles must not operate over H15–44 bridges: 3-S2 (5 axles) with wheelbase less than 38 feet; 2-S1-2 (5 axle) with wheelbase less than 45 feet; 3-3 (6 axle) with wheelbase less than 45 feet; and 7-, 8-, and 9-axle vehicles regardless of wheelbase.

The Federal government, on the interstate system, limits single axle loads to 20,000 pounds, tandem axle loads to 34,000 pounds and the overall gross weight of the vehicle to 80,000 pounds (FHWA, 1984). These loads may legally be exceeded, but only by the purchase of an overload permit from the individual state(s) where the travel will take place (See Chapter V). Additionally, some states which had established higher limits _prior_ to the federal standards were allowed to keep those limits under a "grandfather" clause. These are detailed in Appendix E.

As an example of the application of the bridge formula, suppose a 3 axle tractor is pulling a 2 axle semitrailer. Figure 12 defines this configuration; the dimensions between the axles are unknown, but will govern the legal load that may be carried. This design exercise will determine the dimensions required.

Looking first at the tandem axles on the rear of the semitrailer, the bridge formula shows that unless they are spread more than 8 feet, the total load on the two axles can not exceed 34,000 pounds, nor may the load on either axle exceed 20,000 pounds. The same analysis holds true for the tandem drive axles on the tractor.

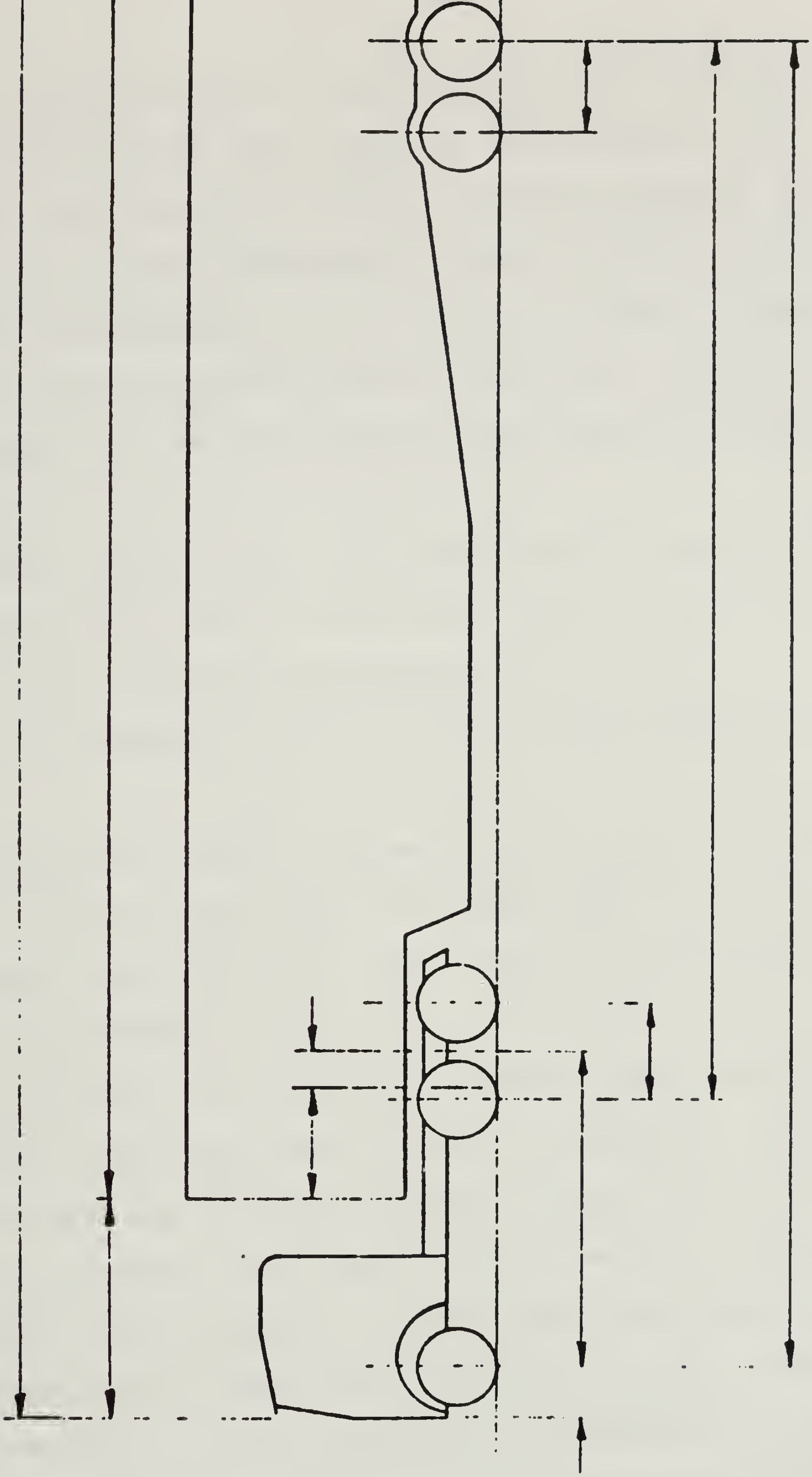


Figure 12. Truck Planning Schematic
Source: Pederson, 1989

However, looking at the 4 axles together (the two drive axles on the tractor and the two rear axles on the semitrailer), and assuming a total dimension between the frontmost axle and the rearmost of these tandems of, say 34 feet, the calculations at 34 feet and 4 axles indicate an allowable load of 64,500 pounds, some 3,500 pounds under the capacity of the two tandem axles loaded to 34,000 pounds each.

The distance between the first and last axle would have to increase to 39 feet to allow the use of the 34,000 pound allowable loads on each tandem axle.

A specific exception to the bridge formula, however allows:

"...Two consecutive sets of tandem axles to carry a gross load up to 34,000 pounds each providing the overall distance between the first and last axles...is 36 feet or more..." (FHWA, 1984).

The next check is to add the steering axle into the computations, which provides 5 axles. A possible dimension from steering axle to rearmost trailer axle is 58 feet; with a distance of 58 feet and five axles, an allowable weight of 84,000 pounds is computed. The Interstate system, however, is restricted to 80,000 pounds without special permits. As it is desirable to operate without special permits, it would be optimal to have 34,000 pounds, the legal limit, on each of our tandem axles and 12,000 pounds on the single steering axle.

This translates into a distance of not less than 51 feet between 5 axles with an 80,000 pound limit, not less than 36 feet separation for 4 axles and a 68,000 pounds limit and not less than a 4 foot separation for a tandem axle with a 34,000 pound limit.

Perhaps not surprisingly, these dimensions and limits are among the most common in use today. It must be emphasized, however, that permits may be purchased to exceed these limits.

The Surface Transportation Assistance Act of 1982 (Public Law 97-424) (STAA) required each state to adopt regulatory standards regarding vehicle width, length and weight on the Interstate and National Network. These standards are:

-not less than 102 inches wide

-not less than 48 feet long for a semitrailer in a tractor-semitrailer combination, or

-not less than 28 feet for a semitrailer in a tractor-semitrailer-trailer combination.

No <u>overall</u> length restriction on a combination is allowed to be set by the states on the interstate.

Note that, although this expressly permits doubles, it does not address triples (three trailers towed by a single tractor). Accordingly, this question has been left to the individual states.

Weights are limited to 20,000 pounds for a single axle, 34,000 pounds on a tandem axle and a maximum gross weight

of 80,000 pounds. Overall weight and axle loadings are subject to the bridge formula.

State Restrictions

The bridge formula presented above is the Federal Bridge Formula, applicable to the interstate system; individual states may adopt regulations either more or less restrictive for their roads. Additional restrictions on length, both of individual components and of overall combinations, exist and vary from state to state. Appendix E lists some of these restrictions by state.

The federal government, under the STAA, requires the states to provide reasonable access to service facilities off of the federal interstate system. The intent is to allow trucks to refuel, off-load or simply be parked for the night without subjecting the operators to charges of violating state restrictions. Most states restrict operations away from the interstate; Appendix E pertains.

An additional restriction which Washington state imposes on trucks is a tire width restriction. It is simple in concept and application; one inch of tire section width must be in contact with the road for each 600 pounds of load. For example, if a four tire axle carries 10,000 pounds, the total lateral tire dimension for that axle must be at least (10,000/600=) 16.6, say 17 inches.

A prospective purchaser of a new truck or trailer must accurately forecast the operating range (what states), the load at which the truck can operate profitably and the size the trailer must be to accommodate that minimum load. Then, the axle spacing must be calculated and the tire arrangement considered to ensure the rig can be legally operated.

The influence the bridge formula has in determining axle spacing and vehicle layout can not be over emphisized. It is the driving force. Any design must be checked against it; if the design does not comply, an illegal vehicle could be built, one that would not be allowed to operate over the highways.

The intent of the above discussion was to show the effect which regulations have in driving the thought process during selection of vehicle components.

Chapter IV

Northwestern Trucker Survey

The Vehicle Maintenance Management Conference (VMMC) is held annually; it attracts a wide variety of trucking industry representatives from the northwest and Canada. The 1989 conference, held at the University of Washington, was the 38th conference.

The results of a survey done in 1988 were made available to the author; the author prepared a similar but modified survey for the 1989 conference. Appendix F contains a copy of both surveys and a summary of the responses summarized in this chapter.

In analyzing the results of the surveys, it is appropriate to first describe the respondents. They cannot be considered a representative cross-section of the industry; they were included only if they attended the conference and only if they took the initiative to pickup and return the survey form.

The results are valid as a kind of 'snapshot' of the industry in the northwest at the time of the surveys. The results presented below should be reviewed with these qualifiers in mind.

In the 1988 survey, the respondents broke into two major groups - those with over 100 vehicles in their fleets and those with under 100 vehicles; in 1989, the number

responding with over 100 vehicles was negligible (1). Accordingly, the data was blocked into three discrete sets: 1988 (over 100 vehicles), 1988 (under 100 vehicles) and 1989.

Because many of the responses were incomplete, the number of responses varies for each question. The number of surveys returned is helpful in evaluating the data. In 1988, 25 responses were returned by people with over 100 vehicles, 34 responses with under 100 vehicles; 1989 responses totaled 24.

As may be seen in Figure 13, straight trucks (no trailers) represent the largest single category (27 percent to 47 percent) of the respondents in both years. Trucks pulling trailers were also a common group (about 20 percent), although semitrailer combinations were a bit more popular (about 25 percent). The majority of the "other" category consists of buses and special use trucks (mostly municipal vehicles), as opposed to any type of train configuration.

It is interesting to note that the larger (>100) fleets consisted mostly of trucks and "other", while the smaller fleets appear more evenly divided among the various types.

The great majority of the respondents in both years operate locally (Figure 14), although about a fifth operate regionally, hauling, say timber or seafood along the coast.

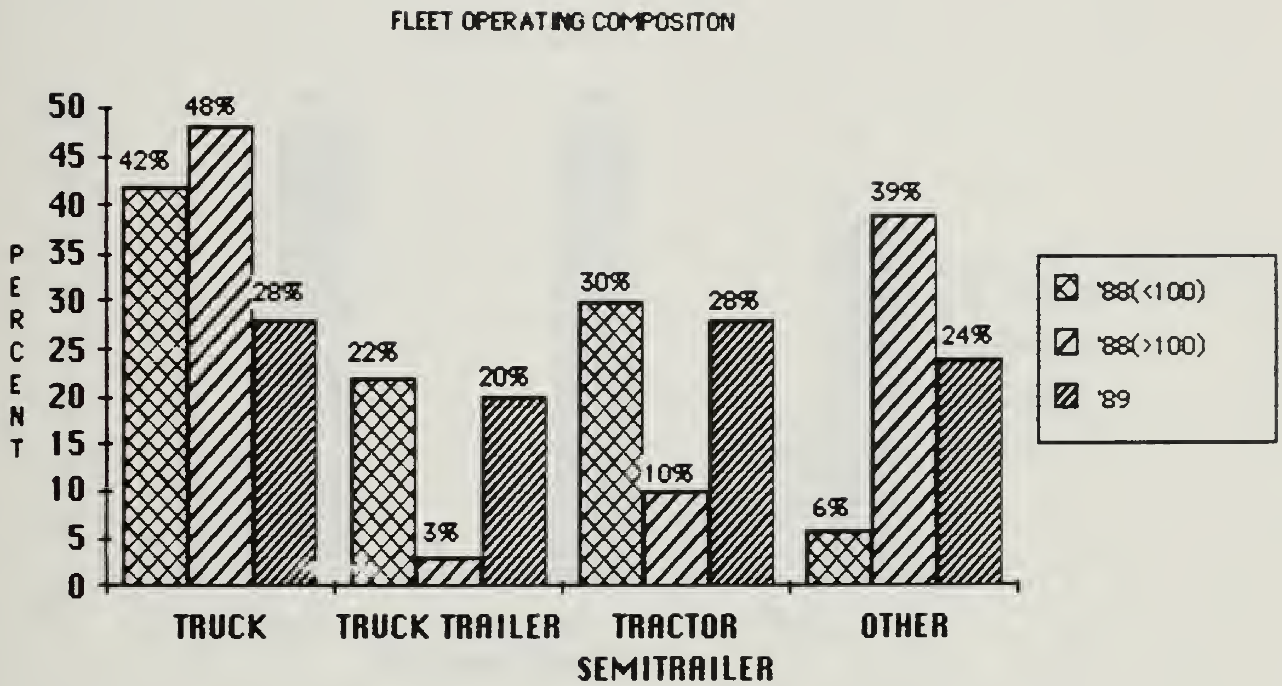


Figure 13. Operating Configuration

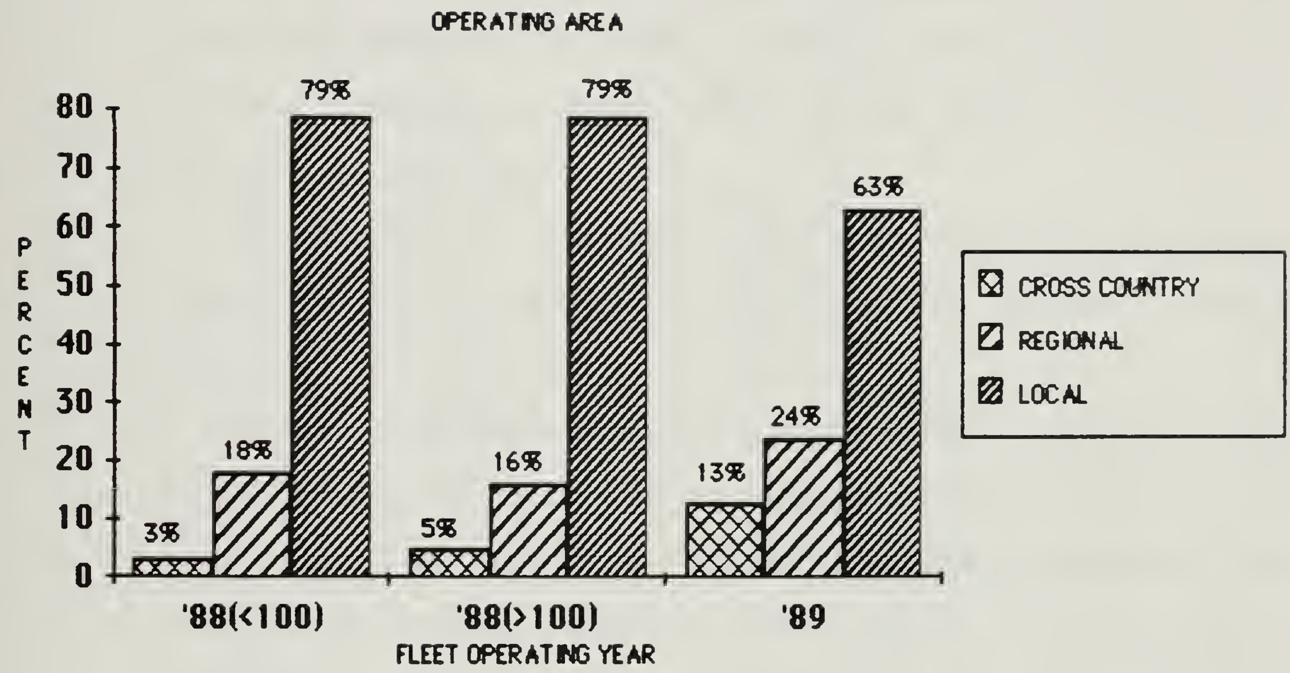


Figure 14. Operating Area

Less than 10 percent of the respondents operate cross country. This may be why the number of straight trucks is so high as opposed to semitrailer rigs, which offer greater cargo capacity.

In 1988, fleet size had little impact on the type of road the trucks were driven on (Figure 15). Urban and rural roads dominated, with about 25 percent of the travel over interstates. In 1989, however interstate and rural driving increases pushed urban travel down to about 25 percent of the total.

In the type of tire used, Figure 16 indicates an almost total switch to radial tires, with few bias ply users left.

Although the data suggests larger fleets are using bias plies often, on the related question "What will you do when it is time to buy new tires?", <u>no one</u> indicated a desire to switch to bias. The vast majority (Appendix F) intended to stay with the same type tire, and 6 of 21, just under 30 percent in the 1988>100 group indicated they would change to radials when their current tires needed to be replaced. A small group indicated an intention to try low profile radials, and a single respondent planned to try super single radials.

Suspension systems on trucks or tractors (Figure 17) emphasized the influence of the logging industry in the survey, with the walking beam being most popular in two out of three of the survey categories. As noted

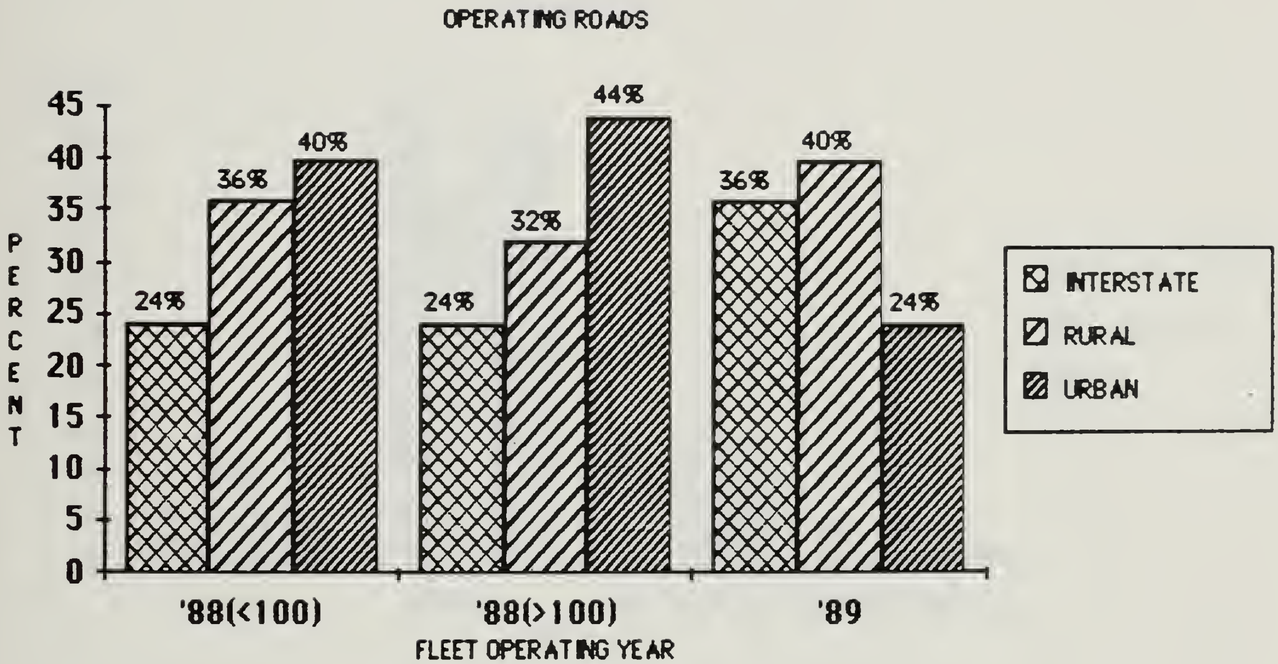


Figure 15. Operating Roads

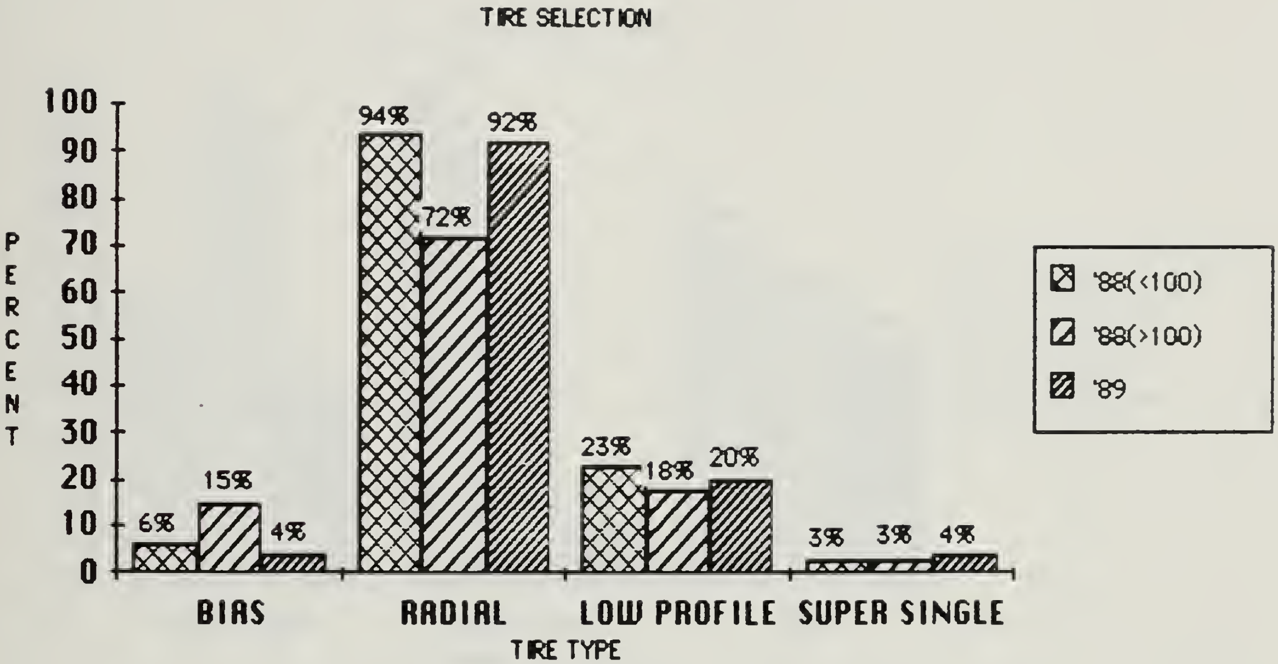


Figure 16. Tire Selection

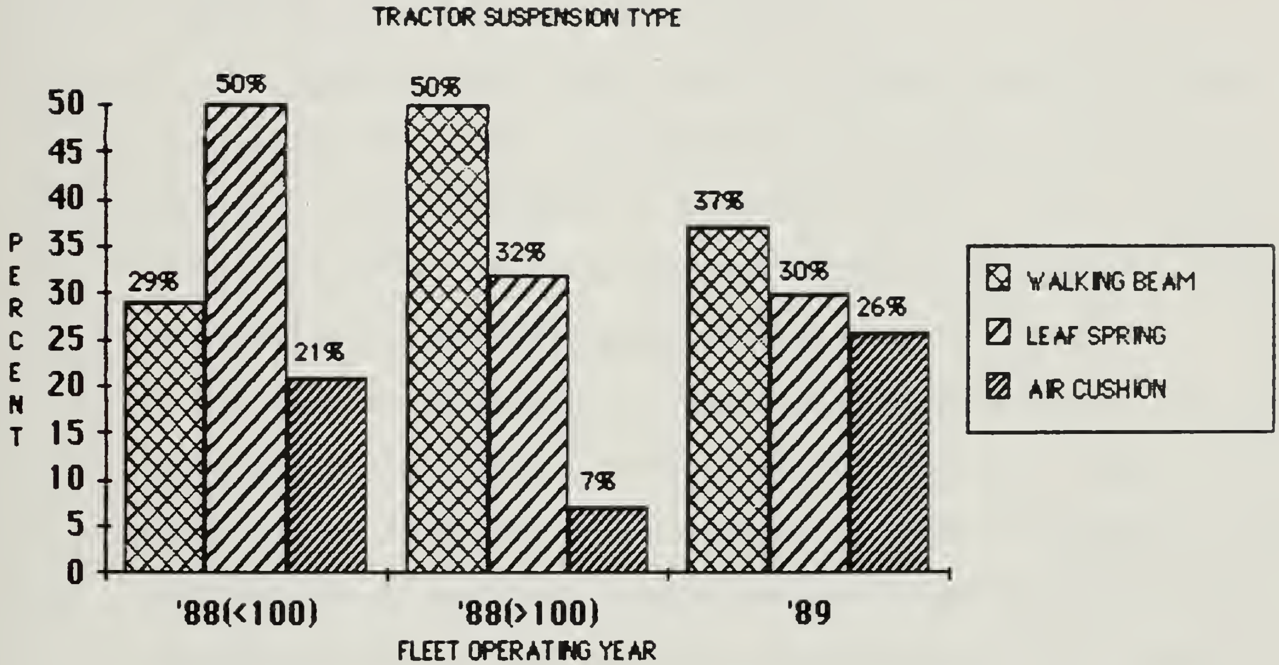


Figure 17. Tractor Suspension Type

previously, the walking beam is often used in on/off road applications, where the quality of the ride is not critical to the cargo (in this case, logs).

Leaf spring suspensions, combining a softer ride with a reasonable service record and no significant weight penalty, were the clear favorite with small fleets in 1988 and, while not the majority in >100 1988 or 1989, held a respectable 30 percent of the market.

Air suspensions, which carry a weight penalty of several hundred pounds compared to other suspensions, were a distant third (about 5 percent) with large fleets. Smaller fleets, perhaps more concerned with comfort, used significantly more air suspensions (20-25 percent).

In looking at trailer suspensions (Figure 18), the leaf spring is the clear choice. In the larger fleets, the leaf spring beat out walking beams by about 10 percent (50 percent to 40 percent) while smaller fleets, perhaps not so dominated by logging, used leaf springs over 70 percent of the time.

This is supported by the industry opinion (Pederson, 1989) that leaf spring suspensions are far and away the dominant suspension for over the road (as opposed to off road) trailers.

Air cushion, while increasing in 1989 over 1988, is still very much in the minority. Air suspensions weigh about 100 pounds more than a leaf spring suspension for a tractor tandem drive axle suspension, about 300 pounds per

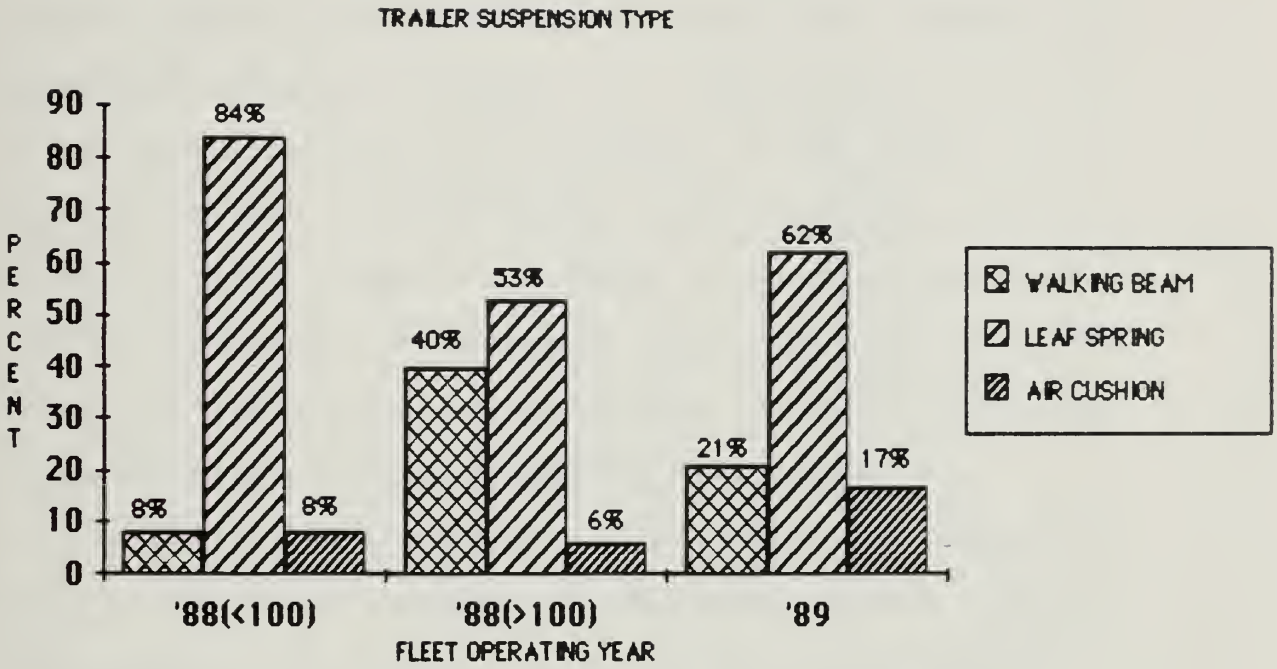


Figure 18. Suspension System Distribution - Trailers

axle more in a trailer application (Pederson, 1989; Ziebal, 1989). As noted earlier, if the operator tends to gross out his vehicle, this weight penalty becomes an on-going income penalty. Viewed another way, the owner pays for the air suspension <u>every time</u> a load is hauled - in lost payload and thus in lost income.

In looking at the response to the gross out/cube out question, about 60 to 70 percent of the fleet grossed out before they cubed out (Figure 19). Accordingly, the lack of air suspensions in the response is not surprising. About 20 percent in 1988 (both groups) and only about 5 percent in 1989 cubed out, while 10 to 20 percent each year did not gross or cube out. This says that 80 to 90 percent of the trucks operating were "filled", either by volume or weight when they were hauling a load.

This lead to the question; "How often <u>are</u> the trucks actually hauling a load?" In response to the question "What percent of time do your trucks operate empty?", about 35 percent of the responsdents claimed less than 10 percent of the time (Figure 20). This was consistent across fleet size and year. A similar result is seen in the midrange (10-20 percent and 20-30 percent).

The over 30 percent category, however, shows a clear breakout. The smaller fleets in 1988 spent more time empty than the larger fleets.

As a general statement, 1989 fleets spent less time empty and more time full than the 1988 fleets.

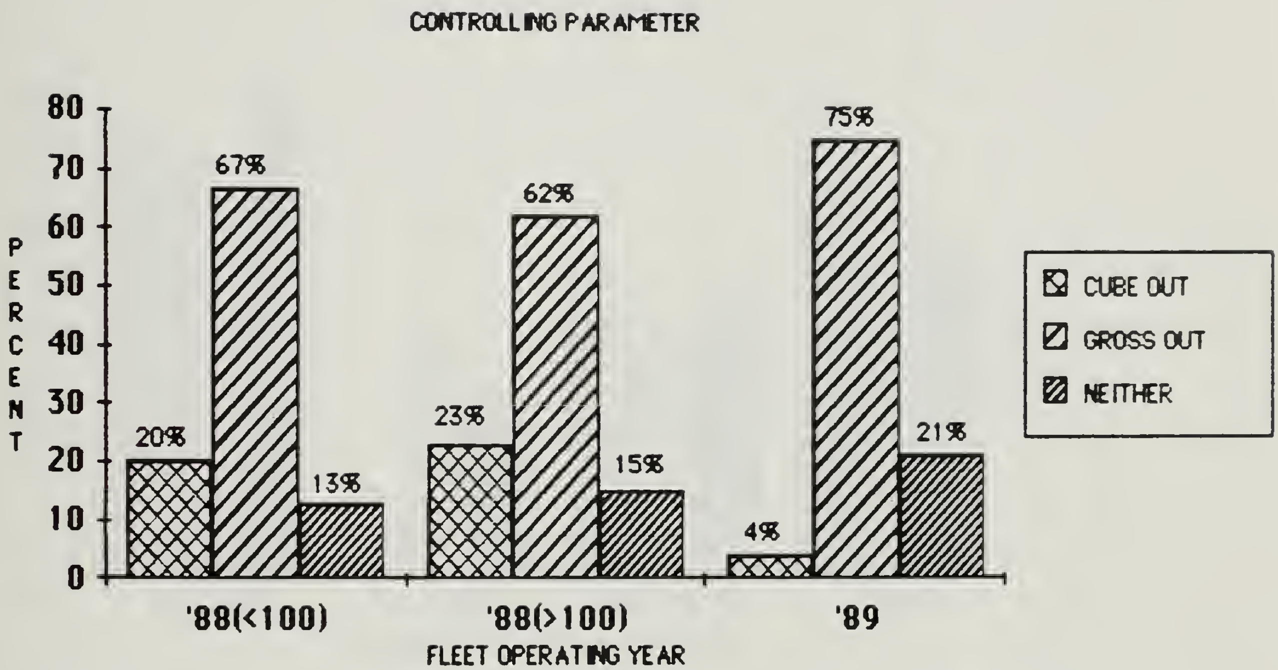


Figure 19. Controlling Parameter

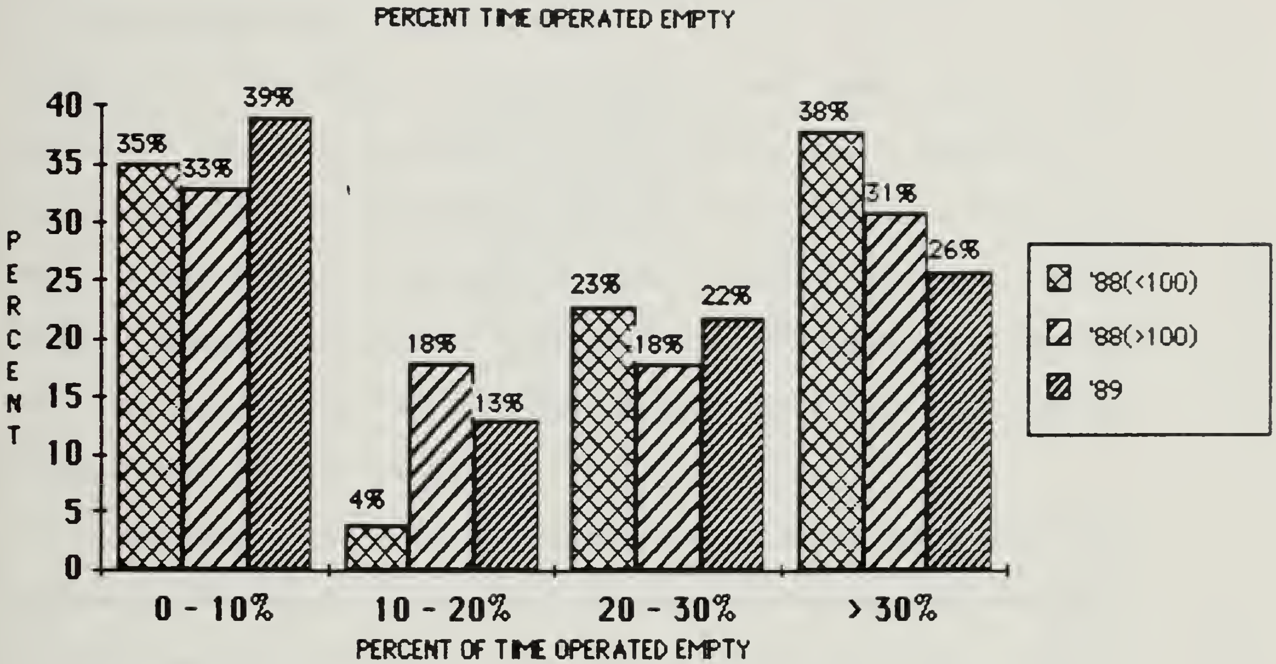


Figure 20. Unloaded Operations

As a truck generates profits only when loaded, it would be nice to conclude that truckers are getting more efficient over time; this may be true. However, because of the nature of the data, this may represent an abundance of truckers in 1988 who rarely carry a return cargo, or it may represent an abundance of shippers in 1989 who do carry return cargo. The sample size is not large enough to draw supportable conclusions.

Several questions in the 1989 survey dealt with ride quality. Asphalt pavement was prefered over concrete by 89 percent of the operators, while 90 percent of them felt their trucks rode "smoother" when loaded as opposed to empty. Speed was also a factor, with 70 percent feeling the ride was better at highway speeds of 55-60 mph rather than in the 30 mph range.

An attempt was made to determine if bias belted tires tracked differently than radial belted tires; 83 percent of the respondents had driven both kinds of tires. Figure 21 illustrates the response; 59 percent felt radials tracked better, while only 4 percent felt bias tires tracked better. Over a third, 37 percent, either had no opinion or did not notice a difference between the types.

As tracking may be greatly influenced by tire alignment, an attempt was made to determine the frequency that alignment was checked. Fully 87 percent check only "when I notice a problem"; 74 percent need alignment when the tires are checked.

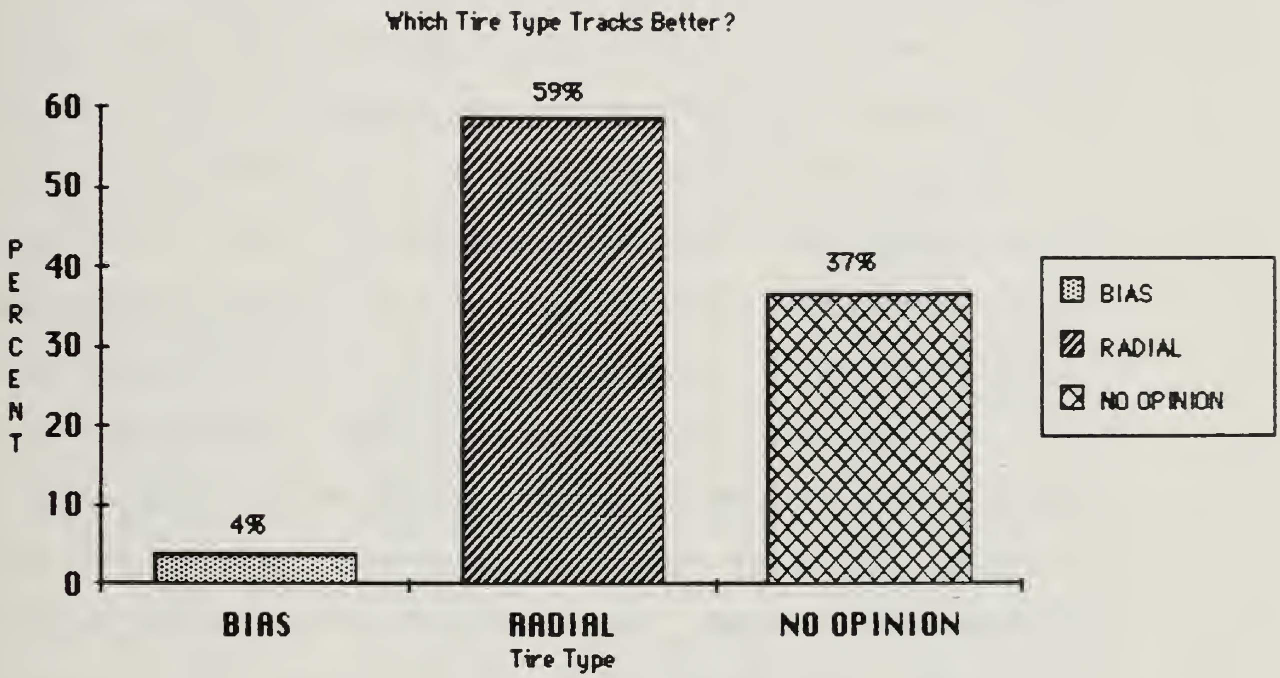


Figure 21. Tire Tracking

Proper inflation pressure is essential to long tire life; only 43 percent of the respondents maintain tire pressure at the maximum recomended pressure, but almost two thirds check pressures weekly.

This is perhaps explained by the finding that 80 percent of the respondents have noticed that ride is affected by inflation pressure; under inflation produces a softer ride, while over inflation produces a hard ride. A side effect of this, however may explain why only 45 percent of the respondents get the rated mileage from their tire tread. Of the "non-achievers", 9 of 9 cited poor driver habits and/or hard use; the "achievers" cited proper maintenance and proper inflation pressures, 7 out of 9 times.

One question asked how many hours per day the fleet trucks were in operation. Figure 22 details the response; over 40 percent (both 1988 and 1989 surveys) claimed to work in excess of 16 hours per day. Many of the responses indicated the trucks operate 24 hours per day. While this may indicate that the trucks <u>sometimes</u> operate for 24 hours at a stretch, the survey asked a simple question. It would be reading too much into it to call this a "bravado" response, but truckers have sometimes been described as "the last cowboys" (Ziebell, 1989). Driving and maintaining trucks is a hard job, requiring dedication and long, often irregular hours. It should not be surprising to find that many of the respondents think of themselves as "on duty" 24 hours a day.

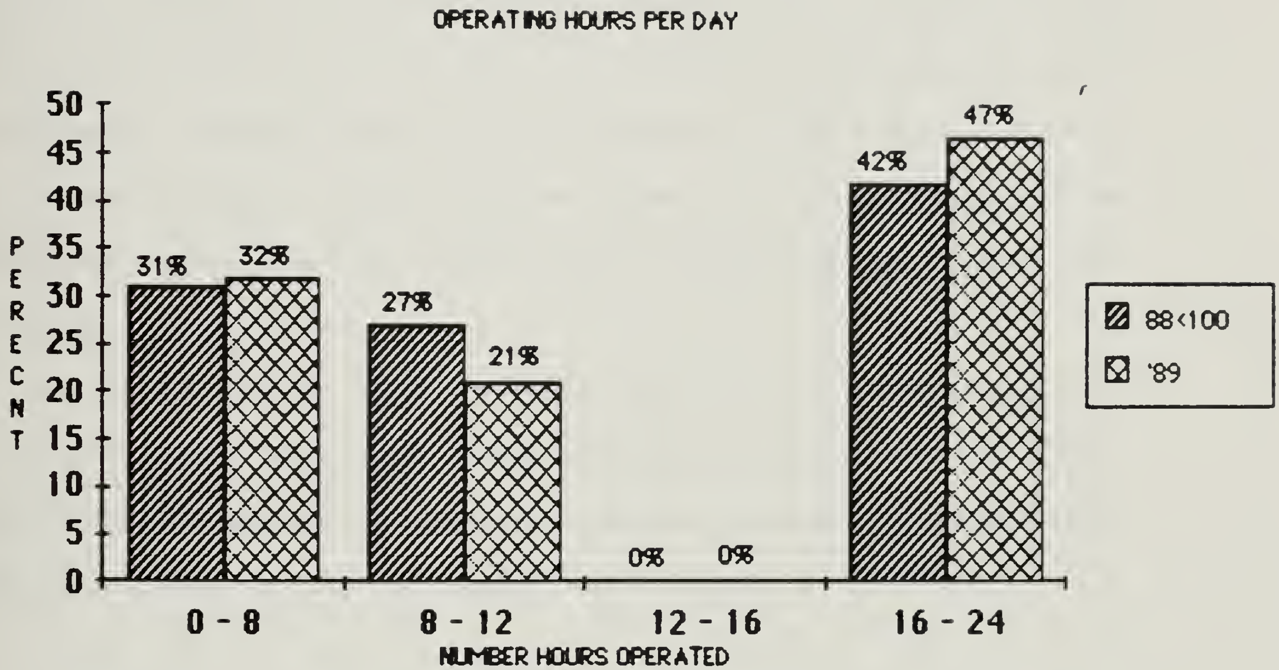


Figure 22. Working Hours

Summary

As a snapshot of the participants, the survey shows a remarkable similarity over the two years, even considering the differences in fleet sizes and individual attendance. Most of the vehicles are either straight trucks or tractors with a semitrailer. Most of the tractors have either walking beam or leaf spring suspensions, while a clear majority of the trailers have leaf springs. Radial tires are used almost exclusively; low profiles are beginning to be seen. Super singles do not seem to be a major factor in the industry, nor do they seem to be gaining. Bias belted tires are rare, and indications are they will get rarer.

Most of the driving is done locally, on both urban and rural roads, although interstate use increased in 1989. Generally, operators reached weight limits (grossed out) before they ran out of room (cubed out).

CHAPTER V

Weights, Dimensions and Enforcement

In any given state, a truck operator or trucking firm must comply with numerous regulations and restrictions. Licenses for the trailer, the tractor and the driver are required; a log must be kept detailing how many miles are driven on what days in which state so each state may collect the appropriate share of road use tax. A record of how much fuel was purchased and where must also be maintained so fuel taxes may be collected. The Interstate Commerce Commission becomes involved when a truck is available for hire - another license is required.

This process is replicated in each state the truck will operate in; a fifteen state operating area requires complying with fifteen separate state laws.

The intent of this section, however is not to focus on all operating permits, but to look at a very specific area of permits - the overload permit.

As noted earlier, it is common practice to design a pavement based on the equivalent number of 18,000 pound axle loads expected during the design period.

A simple relationship often cited between loads and pavement distress is the 4^{th} power "law": any load in excess of 18,000 pounds per axle will cause damage not in a

linear fashion (i.e. - twice as heavy = twice as much damage), but in an exponential fashion (i.e. - a 36,000 pound axle will do $[36{,}000/18{,}000]^4 = (2)^4 =$ 16 times the damage of an 18,000 pound axle) (AASHTO, 1986).

If the pavement is designed for some particular traffic which equals some number of ESALs, but the designer did not include a consideration of overloads, the pavement will reach the end of it's design life sooner than expected.

Although the Federal government has set a maximum allowable load, both for axle loads (20,000 pounds single, 34,000 pound tandem) and total truck weight (80,000 pounds) on the Interstate system, the states are free to issue permits to exceed these limits if they feel it is necessary. Additionally, any state which had higher loads allowed prior to the federal standards was "grandfathered" and allowed to keep the higher limits (FHWA, 1984).

While each state is different, Washington State law will be used as an illustrative example. The Washington State permit process recognizes the need in the permitting process:

"...To protect the public investment in the roadways and structures of the highway system, ... to protect the motoring public..., to assist haulers and individuals with transportation problems....and to generate revenue to defray...costs of maintaining the highway system..." (WSDOT, 1988).

Justification is required in order to obtain overweight permits; in general, the load must be reasonably nonreducable. Rates are as set by the state; currently, for a 3 axle tractor permitted to 105,500 pounds Gross Vehicle Weight (GVW), the additional tonnage will cost about $940 a year.

Note that this charge is an annual fee, not based on mileage. A special "per mile" permit may also be purchased; this features a scale increasing with increasing weights.

The vehicle is still subject to the state bridge formula limits on axle weights, so most tractor - semitrailer rigs with overweight permits will have additional axles.

By looking at the bridge formula values for Washington state (Table 3) it is evident that additional axles must be added and the combination length must increase.

If a truck will exceed size restrictions in complying with the bridge formula weight restrictions, an oversize permit must be purchased. In Washington, the size restrictions are:

-8 1/2 feet wide x 14 feet high x 40 feet (single unit) or

- 48 feet (single trailing unit) or

60 feet (two trailing units).

The same logic applies to size as to weight; the load must be reasonably nonreducable. If the load cannot reasonably be reduced, it may be transported <u>even if the</u>

Table 3. Washington State Vehicle Weight Limits
Source: "Overweight Permits", WSDOT, 1988.

VEHICLE WEIGHT TABLE

Section 46.44.041

As Last Amended by HB No. 1470, 1988 Session

No vehicle or combination of vehicles shall operate upon the public highways of this state with a gross load on any single axle in excess of twenty thousand pounds, or upon any group of axles in excess of that set forth in the following table, except that two consecutive sets of tandem axles may carry a gross load of thirty-four thousand pounds each, if the overall distance between the first and last axles of such consecutive sets of tandem axles is thirty-six ft. or more.

Maximum load in pounds carried on any group of 2 or more consecutive axles

Distance in feet between the extremes of any group of 2 or more consecutive axles	2 axles	3 axles	4 axles	5 axles	6 axles	7 axles	8 axles	9 axles
4	34,000							
5	34,000							
6	34,000							
7	34,000							
8	34,000	42,000						
9	39,000	42,500						
10	40,000	43,500						
11	S	44,000						
12	E	45,000	50,000					
13	E	45,500	50,500					
14		46,500	51,500					
15	N	47,000	52,000					
16	O	48,000	52,500	52,500				
17	T	48,500	53,500	53,500				
18	E	49,500	54,000	54,000				
19		50,000	54,500	54,500				
20	B	51,000	55,500	55,500				
21	E	51,500	56,000	56,000				
22	L	52,500	56,500	56,500				
23	O	53,000	57,500	57,500				
24	W	54,000	58,000	58,000				
25		54,500	58,500	58,500				
26		55,500	59,500	59,500				
27		56,000	60,000	60,000				
28		57,000	60,500	61,000	61,000			
29		57,500	61,500	62,000	62,000			
30		58,500	62,000	63,000	63,000			
31		59,000	62,500	64,000	64,500			
32		60,000	63,500	65,000	65,000			
33			64,000	66,000	66,000			
34			64,500	67,000	67,000			
35			65,500	68,000	68,000			
36			66,000	69,500	69,500			
37			66,500	70,500	70,500			
38			67,500	72,000	72,000			
39			68,000	72,500	72,500			
40			68,500	73,000	73,000			
41			69,500	73,500	73,500			
42			70,000	74,000	74,000			
43			70,500	75,000	75,000			
44			71,500	75,500	75,500			
45			72,000	76,000	76,000			
46			72,500	76,500	80,000	80,000		
47			73,500	77,000	81,000	81,000		
48			74,000	78,000	82,000	82,000		
49			74,500	78,500	83,000	83,000		
50			75,500	79,000	84,000	84,000		
51			76,000	80,000	84,500	85,000		
52			76,500	80,500	85,000	86,000		
53			77,500	81,000	86,000	87,000		
54			78,000	81,500	86,500	88,000	91,000	91,000
55			78,500	83,000	87,500	89,000	92,000	92,000
56			79,500	83,000	87,500	90,000	93,000	93,000
57			80,000	83,500	88,000	91,000	94,000	94,000
58				84,000	89,000	92,000	95,000	95,000
59				85,000	89,500	93,500	96,000	96,000
60				85,500	90,000	95,000	97,000	97,000
61				86,000	90,500	95,500	98,000	98,000
62				87,000	91,000	96,000	99,000	99,000
63				87,500	92,000	97,000	100,000	100,000
64				88,000	92,500	97,500	101,000	101,000
65				88,500	93,000	98,000	102,000	102,000
66				89,500	93,500	98,500	103,000	103,000
67				90,000	94,000	99,000	104,000	104,000
68				90,500	95,000	99,500	105,000	105,000
69				91,000	95,500	100,000	105,500	105,500
70				92,000	96,000	101,000	105,500	105,500

NOTE: It is unlawful to operate upon the public highways any single unit vehicle supported upon 3-axles or more with a gross weight including load in excess of 40,000 lbs. or any combination of vehicles having a gross weight in excess of 80,000 lbs. without first obtaining an additional tonnage permit as provided for in RCW 46.44.095. PROVIDED, That when a combination of vehicles has purchased license tonnage in excess of 72,000 lbs. as provided by RCW 46.16.070, such excess license tonnage may be applied to the power unit subject to limitations of RCW 46.44.042 and this table when such vehicle is operated without a trailer.

The Gross Weight of vehicle and load shall not exceed 600 lbs. per inch width of tire.

The Overall Width of vehicle and load shall not exceed 8 feet 6 inches.

The Overall Height of vehicle and load shall not exceed 14 feet.

The Overall Length of any single vehicle shall not exceed 40 feet with or without load.
Single Trailer Length 48 feet.
Double Trailer Length 60 feet.
Truck & Trailer length 75 feet.

WHEN INCHES ARE INVOLVED: Under six inches take lower. Six inches or over take higher.

The maximum load on any axle in any group of axles shall not exceed the single axle or tandem axle allowance as set forth above.

The maximum axle and gross weights specified in this table are subject to the braking requirements set up for the service brakes upon any motor vehicles as provided by law.

It is unlawful to operate any vehicle upon the public highways equipped with two axles spaced less than seven feet apart, unless the two axles are so constructed and mounted that the difference in weight between the axles does not exceed three thousand pounds. However, variable lift axles are exempt from this requirement. For purposes of this section, a "variable lift axle" is an axle that may be lifted from the roadway surface, whether by air, hydraulic, mechanical, or any combination of these means. The weight allowed on the axle is governed by RCW 46.44.042 and this section.

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legal limits are exceeded if certain conditions are met. In Washington, those conditions are:

Weight on a single axle: < 22,000 pounds.

On a tandem axle: < 43,000 pounds.

Weight on any series of axles is subject to the following restrictions:

Distance Btwn. Axles (feet)	Weight Allowed
0 - 10	Feet x 6500
10 - 30	Feet plus 20 x 2200
Over 30	Feet plus 40 x 1600

The lesser of these governs. This is less restrictive (allows more weight) than the bridge formula and is used for loads up to 200,000 pounds.

As an example of the permitting process, assume a load of 67,000 pounds (say a precast concrete bridge beam) which is 80 feet long. Assume a vehicle tare weight of 30,000 pounds, and assume the load will be evenly distributed over the axles, with the exception of the steering axle, which will carry 12,000 pounds.

With a GVW of (67,000 + 30,000) 97,000 pounds, an overweight permit will be required. In order to carry this load, the total length will need to be at least 54 feet with 8 axles, or 45 feet with 9 axles. As the cargo is 80 feet long, length will not be a limiting factor; an oversize permit will already be required.

Using the values in Table 3, various combinations of single, tandem and tridem axle solutions can be found.

One possible solution would be a tridem on the rear, spread over 12 feet (limit is 45,000 pounds), a lift axle added to the drive tandem, which creates another tridem (limit also 45,000 pounds) and 12,000 pounds on the drive axle. The rear tridem would need to be at least 52 feet away from the drive axle tridem (97,000 total - 12,000 (on the steering axle) = 85,000 pounds on the two tridems. The limit on six axles at 85,000 pounds is 52 feet; Table 3).

Additionally, the steering axle must be at least 19 feet in front of the lead tridem (42,500 (Tridem) + 12,000 (Steering axle) = 54,500 pounds on 5 axles. Table 3 yields 19 feet). As noted above, numerous axle combinations can be used in determining the most economical method of transporting the beams. Note that adding or deleting axles will alter the vehicle weight itself.

In those cases where a load is in excess of 200,000 pounds GVW, the process becomes more complicated. A special application must be made to WSDOT, which may allow or disallow on a case-by-case basis. The Washington law is exemplary in calling for case specific tests on the proposed route, including CBR tests, so the state can make an informed decision. It is importent to note that loads of this size may move, but an informed decision can be made.

Current Washington state law (RCW 46.44.047) allows for special exemptions for the logging industry, although these exemptions do not impose exceptionally heavy loads

on the pavements. These exceptions do, however, point out the prospective role that local politics can play in allowing heavy loads which a designer may not have foreseen at the time of design. While perhaps necessary and desirable from a political or economic development standpoint, such practices must be made in an informed atmosphere.

Washington also has a "load per inch of tire width" limit; it is currently 600 pounds per lateral inch. In practice, this means a 20,000 pound axle load must have at least 34 lateral inches of tire on the road; a 12,000 pound load requires 20 inches. Although it is a simple, easily understood requirement, and would appear to make much sense as a means of spreading the load, just over half of the states (27) have such a requirement (ATA, 1989).

As in any restrictive program, some people will not comply at all, while others will comply only occasionally. Overweight trucks, some permitted, do operate on the highways. If pavements are not designed to take this into account, they will fail - not prematurely, but before anticipated. They will simply reach the design ESAL limit sooner then planned.

Washington State Patrol

The Washington State Patrol (WSP) is in the position of interpreting and enforcing the laws and regulations enacted by the federal and state governments in the field.

The WSP is empowered on all federal and state roads, and has authority on county and city roads if authorized by the county or city.

The patrol devotes a portion of itself to trucks, the "Commercial Vehicle Enforcement" section. The mission of this section is to ensure that trucks and operators are at all times in compliance with the law. Several different modes are used to accomplish this mission.

It should be noted that this chapter is the interpretation of the author of the role the State Patrol plays. While it is based on interviews, discussions, literature and field work with the patrol, it is not intended to be an official representation of their responsibilities.

Permanent Weigh Stations

The patrol operates 58 permanent weigh stations around the state, located as shown in Figure 23. The scales are located on major points of entry into the state and at strategic locations throughout the state. The intent is to filter the most truck traffic with the fewest scales. A WSP trooper from Commercial Vehicle Enforcement (CVE) observes the scales and detains overweight trucks for citation.

While the scales are open as much as possible, economics and labor restraints dictate the actual operating hours. The scales are open on a random basis, and all commercial trucks must stop if the scales are open.

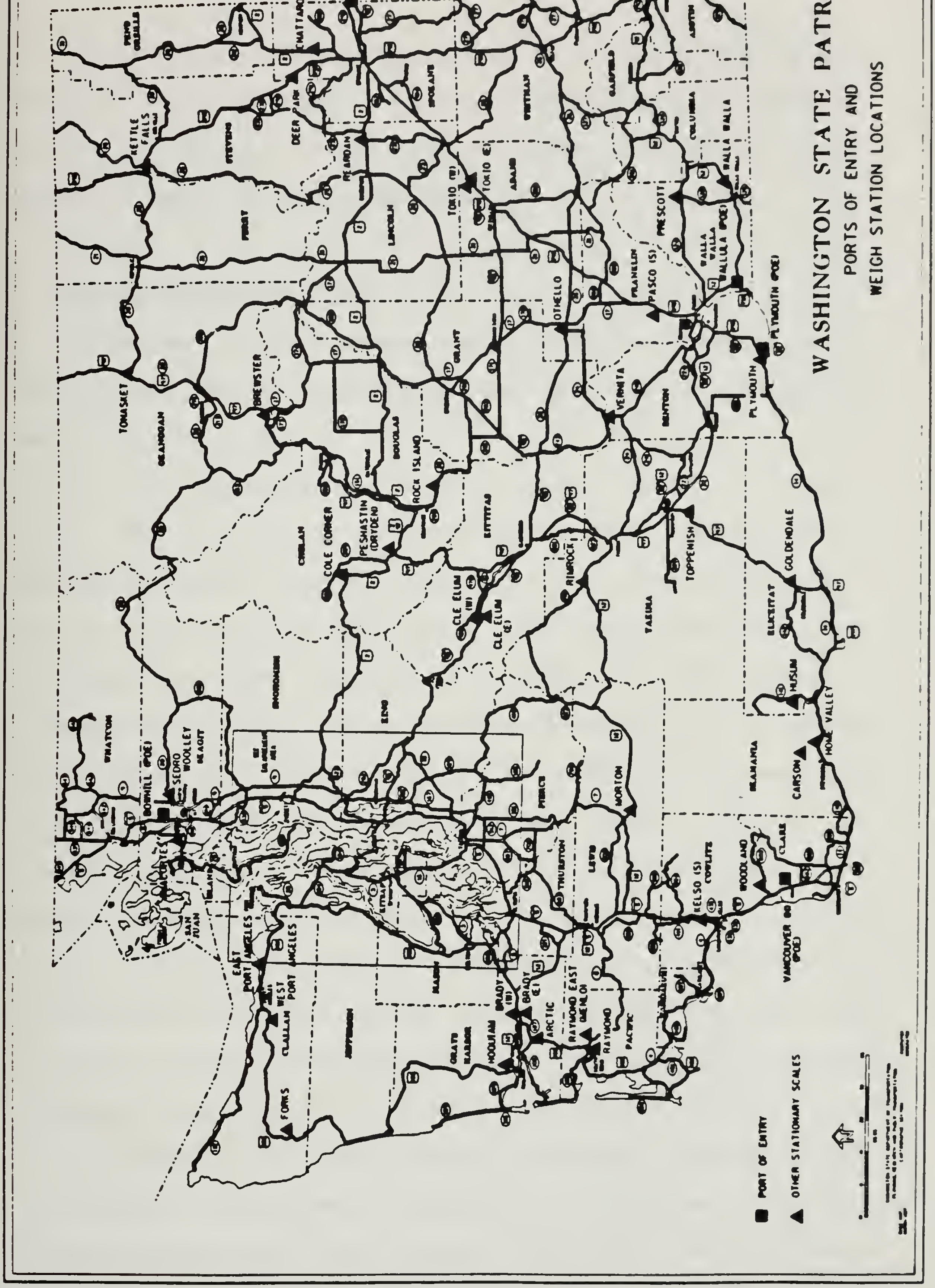


Figure 23. Washington State Patrol Weight Station Locations
Source: Washington State Patrol

A commercial truck is defined as having a GVW in excess of 10,000 pounds. If a truck does not stop, that is in and of itself a violation of state law, even if the truck is legal in all other aspects.

Mobile Weigh Stations

Alternate routes around weigh stations exist, and if an operator has an overweight vehicle, an alternate route may be chosen.

The WSP has purchased several sets of portable scales, which are carried in WSP minivans. These mobile weigh stations randomly patrol roads around the state and (randomly) select trucks for checks. The checks performed are identical to those performed at a permanent weigh station. The patrol operates numerous mobile stations; they consist of a trooper, a set of scales for weighing, a measuring tape and toolbox for inspections and several radios for communications. These patrols operate throughout the state, attempting to target those areas which attract truck traffic. Trucks are stopped based on the troopers discretion and visual clues; a truck heaped high with top soil may not be overweight, while a truck partially loaded with concrete rubble may be well over a load limit.

In addition to weight checks, a visual inspection of the vehicle for safety violations is conducted; this includes looking for wheel cracks, bald tires, worn brakes, misaligned suspension springs and frame weaknesses. The

operators licence, registration and insurance is checked, as is his medical card (a card from a physician stating the operator is physically fit to operate a truck).

Enforcement Action

The trooper on duty has a large amount of discretion in deciding on the appropriate action to take if an infraction is found. The trooper can issue warnings, either verbal or written, or citations. Citations carry a fine and a court date, while warnings carry neither.

In extreme situations, either of safety or weight violations, a trooper may detain a vehicle on the spot until it can be brought into compliance through on-the-spot correction. Correction can range from shifting cargo inside the trailer (to unload an overloaded axle) to moving the fifth wheel (if it is moveable) to calling for another truck so cargo can be transferred.

In the event a load is permited but is so heavy as to be in violation of the permit, the patrol may revoke the permit (RCW46.44.105, WASHDOT Permits, 1988).

Of vital importance to the operators, safety citations issued by the WSP are counted as moving violations by both the state licensing department and insurance companies. Drivers who have never had an accident, but have been operating an unsafe vehicle several times could lose their insurance or have large premium increases. Safety violations also carry a $45 fine (Fouty, 1989; WSDOT, 1988).

Overweight violations, while not a moving violation for insurance or licence purposes, carry a substantial fine. The fine increases with the size of the violation. It is importent to note that the ticket is issued to the <u>driver</u> of the truck, not the owner of the truck. Additionally, three or more violations result in license revocation.

Recognizing that a driver often has little or no say in how heavy the truck is, especially if driving for a company, some individuals favor differentiating between "individual" violations and "corporate" violations. The goal is to punish whomever is overloading the trucks, instead of simply the operator.

The operator may be subject to loss of employment by the company for refusing to drive an overweight truck, while driving it means running the risk of losing licence, insurance, fines or some combination thereof. If the <u>company</u> is the decision maker, an "overticketed" driver will simply be fired by the company when no longer useful and a new driver hired; the cycle will then repeat itself (Fouty, 1989).

It should be noted that this practice was <u>not</u> condoned by any of the trucking firms contacted in the research for this report. Many firms pay overweight fines for their operators as a matter of company policy, and strive to comply with all aspects of the law.

One concept proposed to combat this alleged practice is to ticket the companies which operate the vehicles di-

rectly, rather than the drivers. If a company collects enough fines, it will be motivated to comply with the law. This is not current practice in Washington, nor has it been formally proposed.

Many load violations, based on conversations with operators, are based on ignorance of the law or of the weight of the specific cargo they are carrying, instead of intentional violations. The operators learn with experience how much they can carry without violating the law. Some carriers now use load scales when loading, while others simply "eyeball" the loads. This (eyeballing) is especially common in field loading of dump trucks hauling rubble or fill material (Fouty, 1989).

A certain amount of overloading, however is intentional; sometimes blatant. On July 21, 1989 (the day the author rode with the WSP) a trooper stopped a 6 axle tractor semitrailer combination which was approximately 49,000 pounds over the legal limit of 80,000 pounds. The driver was hauling a large piece of construction equipment. The construction equipment was a known weight and the number of axles on the rig was known. As was shown in Chapter III, it is a simple matter to calculate that, at a minimum, an overweight permit was required. In fact, a differently configured vehicle would have been required to legally move this load. The violation resulted in a $1,500 fine.

Strategy

The weigh stations are located so as to intercept most interstate traffic as it enters the state; any overweight truck is then stopped before it has driven far on state roads. If an overweight or overlength permit is required, they may be purchased at these "point of entry" (POE) weigh stations. Non POE stations do not sell the permits, so an operator must visit a designated sale point if the POE weigh station is closed (Fouty, 1989; WSDOT, 1988).

In addition to the weight checks, state personnel at the permanent weigh stations will randomly select trucks and inspect them for proper paperwork (operators log, licence, insurance, permits, registration, etc.), or conduct a safety check of the rig (tires, wheels, suspension, axles, frame, exhaust, chassis labels, lights, wipers, dimensions, mirrors, etc.).

These checks occur at random, at weigh stations located throughout the state, which are themselves open at random, and by the mobile weigh station patrols. As a result, a trucker may be weighed and inspected at any time while driving.

Damage Recovery

The state has instituted a process of fining truck operators for overweight violations. Fines are set at nominal amounts ($50 to $100), but an excess poundage fine

of three cents per pound is also charged. Additionally, with two violations in a twelve month period the court may suspend the license registration; with three violations, the court shall suspend license registration (WSDOT, 1988).

Appendix G contains a summary of the fines assessed in Washington in calendar years 1987 and 1988. In 1988, approximately 1.7 million vehicles were weighed; 3,384 were overweight by GVW, 16,108 had an axle overweight, 305 exceeded tire width limits and about 80,000 had dimensional or equipment violations. They were fined a total of about $2.6 million. In 1987, 1.5 million vehicles were weighed with 2,482 found overweight by GVW and about $2.1 million in fines.

These numbers reflect only those overweight vehicles stopped by the patrol, not the actual frequency of overloading. While they show a low rate of violation (about 0.2 percent in 1988, about 0.16 percent in 1987), it is important to recognize the disproportionate amount of damage they may be doing. Assuming the 4th power rule applies, 0.2 percent of the truck traffic may be accounting for a much higher percentage of the damage.

Limitations

As in any enforcement action, a great deal of discretion is available to the individual WSP trooper. While official rules exist, it is common to allow some overage

on weights, whether as a fixed amount (say 200 pounds) or as a percentage of the allowable weight (20,000 pounds + a percent). These situations are handled with a warning, either verbal or written. This exists partly because the troopers recognize that honest, minimal mistakes occur when a trucker is pushing the limits, and partly because the troopers recognize the physical limits of the scales. Different scales will weigh the same weight differently, while tire location on a scale also has an impact.

An additional difficulty which the patrol faces is the physical size of the scales they use. The fixed station utilizes a weighing platform which varies in size from site to site, but is often 12 feet long x 12 feet wide. A tandem fits on easily, but a tridem crowds it. Some trucks currently on the road are going to four axle sets in order to meet bridge formula restrictions. If these become more common (under the Turner truck proposal, for example) the existing weigh stations may need to be retro-fitted with larger scales.

The mobile stations use scales which weigh a single tire each - four scales can weigh a set of tandem axles, one at each axle end. The tire is placed under the outer tire, and the truck is driven onto the scale. This raises the inner tire off the pavement and allows the axle to be weighed with only two scales; the total weight is the sum of the individual axle weights. Likewise, the weight of the truck measured on a permanent weigh station scale is

found by summing the weights of the individual axles.

While simple arithmetic (summing the weights) appears to work, some field studies indicate problems. As in any area where an operator can capture a competitive edge by going to the limit, commercial truckers want to load trucks up to or close to the legal limit. When this is done, however, the margin of error may be less than the margin of error on the scale.

A 50,000 pound scale accurate to 1 percent is plus or minus 500 pounds. When possible calibration problems due to rough handling, humidity, heat or mechanical malfunction are included, additional error creeps in. A 3 percent error translates to 1,500 pounds - possibly within the limits trucking companies would like to be operating in.

Appendix H contains excerpts of an industry study performed in 1988 on a WSP scale; it illustrates some of the problems of weighing a truck in parts and summing them.

Trucks sometimes now use scales while loading in order to remain legal; this permits them to load close to the legal limits. Under the best of conditions, some error in the accuracy of the scale exists. As the industry becomes more competitive and cost conscious, and vehicles load close to the legal limits, the differences in scale accuracies may become more critical.

Chapter VI

Observations

Numerous studies of suspension systems, tire types and inflation pressures, axle spacings and other factors are underway. Research is ongoing but the results are so inconclusive at this point it is difficult to make meaningful recommendations. Notwithstanding this, the author wishes to make several observations.

Pavement designers and maintainers - the entire pavement or public works community - need to stop viewing trucks as the "enemy". Several individuals expressed a negative view of trucks in the course of this research, usually with some vague hope that they (trucks) would just go away.

The trucking industry needs to recognize the limits of pavements. Although industry executives and technical personnel understand the consequences of overloading, the average operator is often motivated to "haul the most the fastest"; some view fines as the cost of doing business. Heavy loads <u>do</u> acceleraye pavement distress, and trucks (as opposed to cars) inflict the majority of vehicle caused damage to pavements.

Barring some unforeseen economic or technical breakthrough, asphalt concrete surfaced pavements will constitute the majority of new and rebuilt pavements constructed

in this country in the future. The limits of our present technology in loadbearing capacity may have been reached (WASHTO, 1986); heavier axle or wheel loads may not be supportable. Indeed, a case <u>may</u> be made that present loads are not supportable.

Operating changes by truck operators <u>can</u> affect dynamic axle load impacts; the choice of suspensions, as referenced in Appendix B, can have an influence on dynamic loads. Tire dimensions and inflation pressures influence contact pressures on the pavement. It may be desirable to give operators a choice in the future - lower load limits with some suspensions or tires, higher limits with others. As noted in chapter I, Canada has taken this route to encourage the use of B trains.

Lighter axle loads, but longer combinations - the "Turner Truck" - is an alternative which has received much attention. The concept, while not fleshed out fully, is to allow higher GVW, but require compliance with the bridge formula for axle weights. The bridge formula would itself be revised to restrict loads to some lower limit, say 13,000 pounds per axle. The effect would be to allow larger, longer and heavier combinations, but with lower axle weights then at present. If handling, safety and manufacturing considerations can be resolved, the author believes this to be a workable concept.

All states, or perhaps the FHWA, should adopt some type of tire width restriction, similar to that now in

effect in Washington. Currently, only 27 states have such a restriction.

Tires appear to be a settled issue, in the authors opinion. Radial tires, standard for tractors and low profile for trailers, will be the rule in the future as bias use continues to fade.

The industry will not move to adopt the super single tire instead of dual tires. A radical event, possibly a dramatic increase in fuel prices, will be required and even then the operational concerns will need to be resolved.

Leaf spring suspensions will continue to be popular on trailers, while air cushion will grow in popularity on tractors. Operator comfort, as opposed to necessity, will be the driving force for this trend.

The use of trains will increase. Additionally, longer combination vehicles (LCV) will be used. These may consist of triples, or of quadruples in some situations.

As shown in this paper, a truck is far more complicated than watching one on the highway would indicate. Numerous, sometimes conflicting factors influence the design and operation of these vehicles. By understanding where these factors originate, and the impact they carry, the custodians of our nations pavements may be better equipped to do their job - and more effective in doing it.

APPENDIX A

Various Reports of Interest

While numerous reports from various organizations and countries are available, the author found the following reports to be of particular interest and to provide a good background for pursuing this topic. This is by no means a comprehensive listing, nor is it intended to be representative of the full spectrum of reports. These reports do, however serve as an introduction to some of the pavement loading implications of the factors discussed in the main body of this paper. Sources which are cited as a reference are not also cited here.

1. Deen, R. and Southgate, H., "Effects of Load Distributions and Axle and Tire Configurations on Pavement Fatigue", Research Report UKTRP-85-13, NTIS Report PB86-145133, Kentucky Transportation Research Program, Lexington, KY., May 1985.

2. Heinz, R.E., "Truck Impacts on Pavements", memorandum of 28 March 1988, Federal Highway Administration, U.S. Department of Transportation.

3. Mahoney, J.P., "The Relationship Between Axle Configurations, Wheel Loads and Pavement Structures", SP-765, Society of Automotive Engineers, Warrendale PA, 1988.

4. Marshek, K., Hudson, W.R. et al, "Experimental Investigation of Truck Tire Inflation Pressure on Pavement-Tire Contact Area and Pressure Distribution", Research Report 386-1, Project 3-8-84-386, NTIS Report PB88-218839, Center for Transportation Research, The University of Texas at Austin, August 1985.

5. Peattie, K.R.,"The Influence of Axle Spacing on Flexible Pavement Damage", Research Report No. 54, NTIS Report PB86-232170, University of Newcastle upon Tyne, England, July 1984.

6. Woodle, Clyde., "Highway Structural, Geometric and Safety Needs to Accommodate Future Trucking", Trucking Research Institute, Washington, D.C., 1989.

7. Yap, P., "A Comparative Study of the Effect of Truck Tire Types on Road Contact Pressures", SP-765, Society of Automotive Engineers, Warrendale PA., November 1988.

APPENDIX B

Dynamic Loads as a Function of Suspension Type

As a truck is driven down a road, it responds to the actual road profile. This response results in variations in the actual load applied to the pavement; this variation, which can add to or subtract from the static load, is termed dynamic load.

Many different variables can affect dynamic load, including vehicle weight, speed, tire inflation pressure, road surface type and suspension type.

In a study done in England (Mitchell and Gyenes, 1989), the authors reference several studies in which positive dynamic load is quantified as 10 to 30% of the static wheel load. Additional studies indicate that pavement strains are directly proportional to the dynamic wheel loads applied to the pavement. Accordingly, limiting the dynamic load should limit the pavement stress.

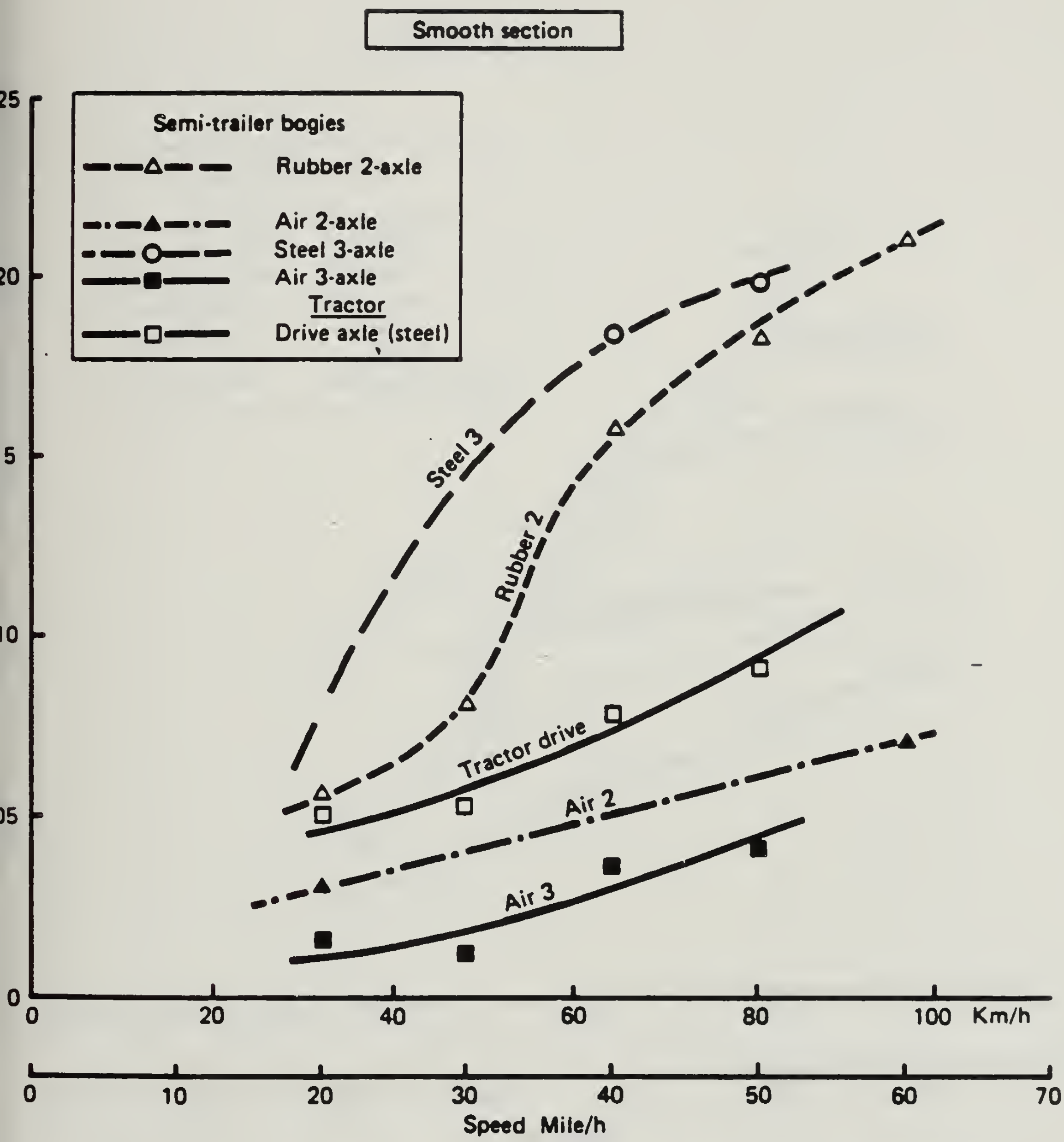
Mitchell and Gyenes compared trucks equipped with air cushion, leaf spring and walking beam (with rubber absorbtion blocks) suspensions over a test track. The track included smooth and rough sections and the test was conducted with the trucks both loaded and unloaded. A portion of their conclusions stated:

> "...At all speeds and on all sections of the track air sprung semitrailer bogies produced lower dynamic loads than steel leaf sprung bogies, while rubber sprung bogies produced dynamic loads that were always higher then those for air bogies, and usually higher then those for steel sprung bogies..."

The authors define a "dynamic load coefficient" as the standard deviation of the dynamic load divided by the static load on the axle or wheel. This was graphed against vehicle speed for different axle locations (drive or trailer) and the different suspensions over smooth, medium and rough pavements. These graphs are reproduced here.

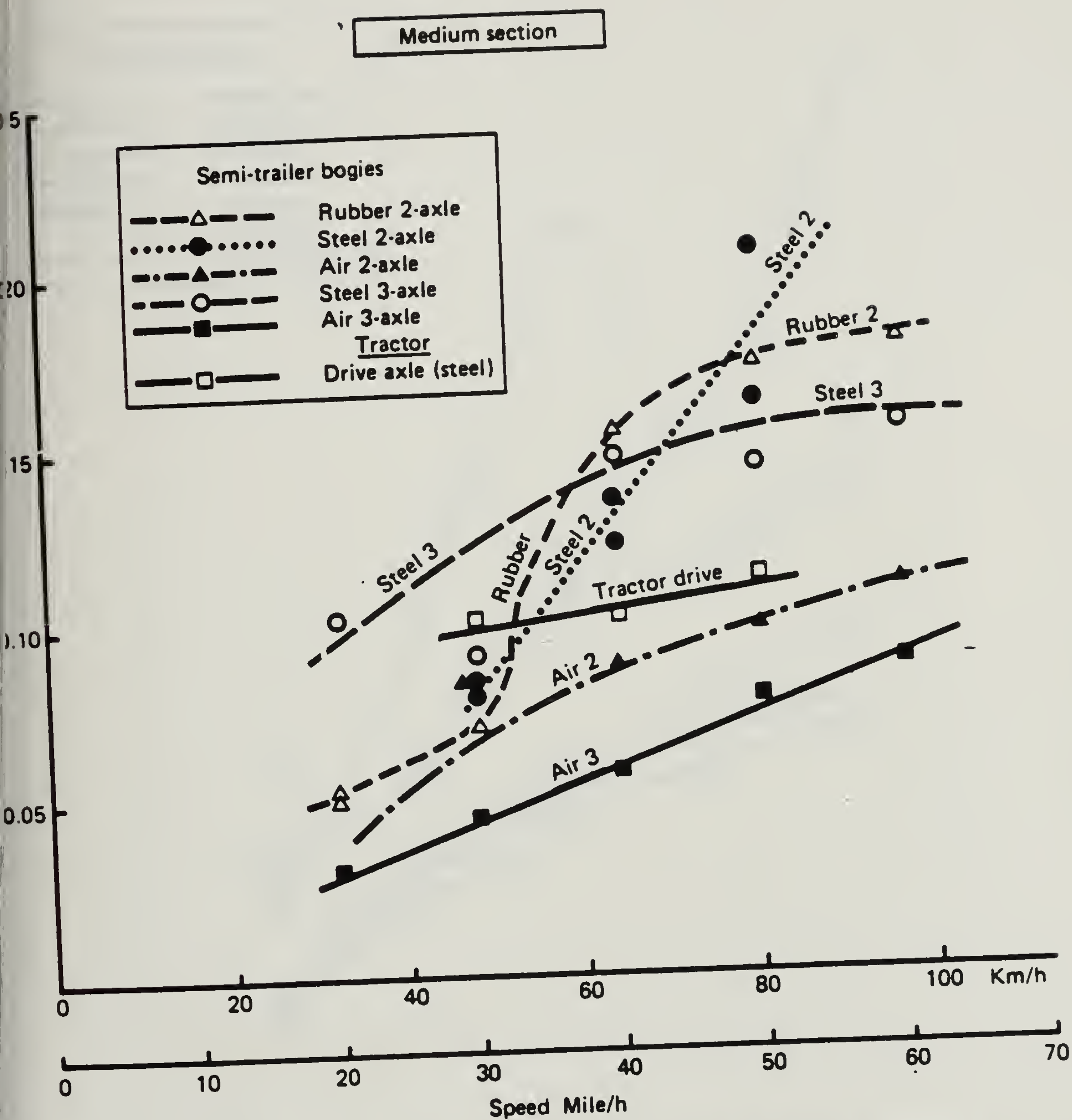
As is obvious, the different suspensions produced differing dynamic loads. This author would like to note that this should be of great interest to pavement designers. If different suspensions offer different loading patterns, will suspension type affect pavement life?

A possible implication of this type of data is in regulation application. By allowing different maximum loads on different suspensions, it may be possible to both maximize hauling capacity and minimize pavement damage. Suspensions which are "kind" to pavements could be encouraged, by higher loads, while suspensions which are "hard" on pavements might have lower limits set.



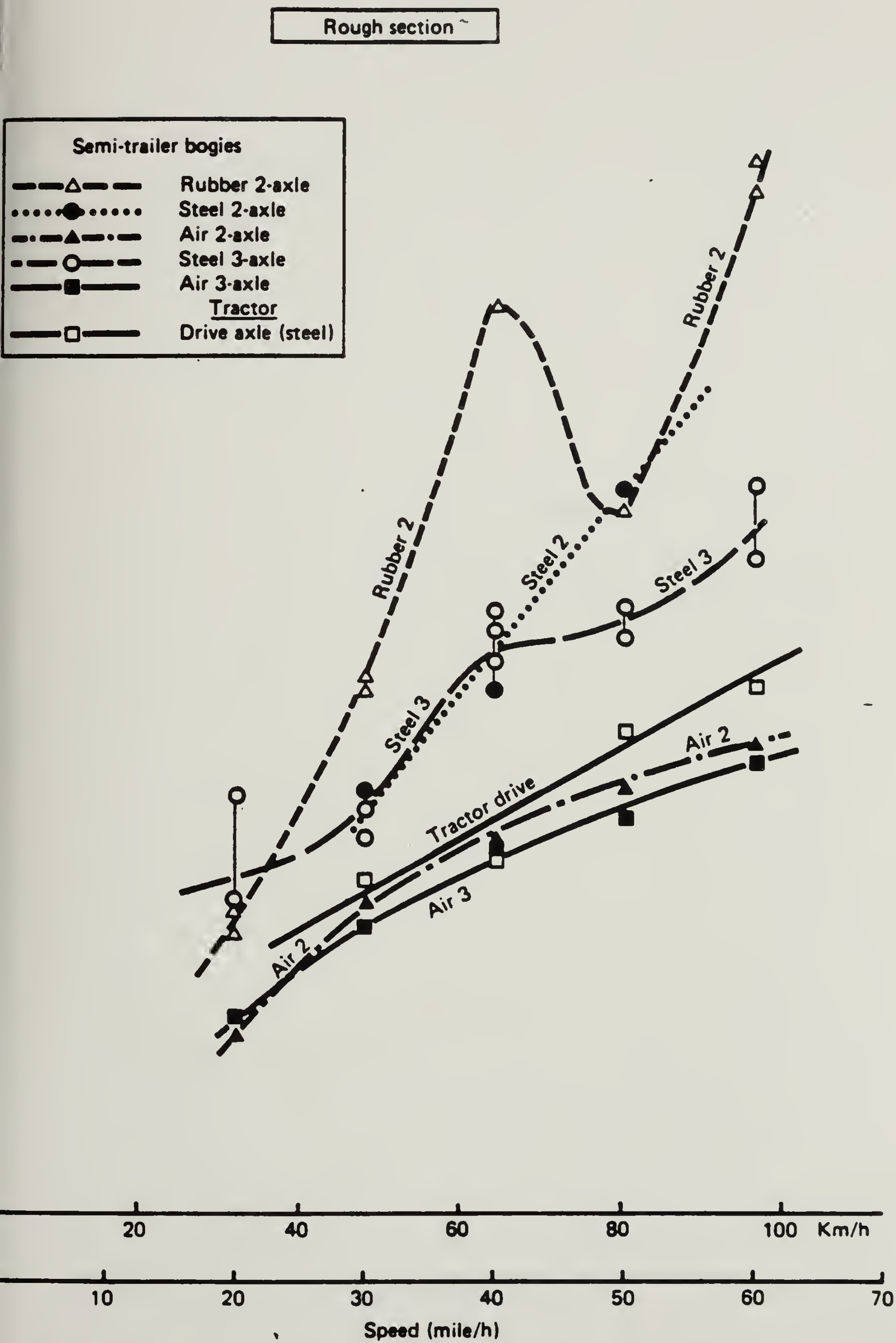
Dynamic load coefficients for the tractor drive axle and 2-and 3-axle semi-trailer bogies on the smooth section of the TRRL track. Vehicles fully loaded

Source: Mitchell and Gyenes, 1989.



Dynamic load coefficients for the tractor drive axle and 2-and 3-axle semi-trailer bogies on the medium section of the TRRL track. Vehicles fully loaded

Source: Mitchell and G yenes 1989.



Dynamic load coefficients for the tractor drive axle and 2- and 3- axle semi-trailer bogies on the rough section of the TRRL track.
Vehicles fully loaded. Source: Mitchell and Gy

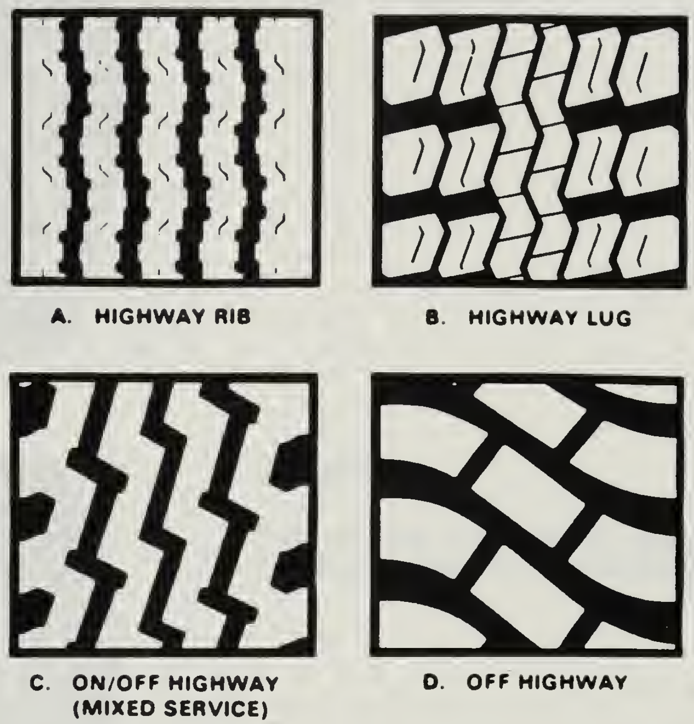
APPENDIX C

Tire Tread Types

While tire tread does not appear to be a major factor in pavement loading characterizations, it is a matter of importance to operators. Different tread types offer different performance characteristics, at different costs.

A tread which gives good traction in mud or snow, for example may offer high rolling resistance on a pavement and reduce mileage.

In general, one type of tread will be used on the steering axle, another on the drive (live) axles and a third on the trailer (dead) axles. A short sample of representative tread types is provided. This information is reproduced from the Michelin Truck & Industrial Tire Data Book, Michelin Tire Corperation, unless otherwise noted.



BASIC TREAD PATTERNS

Source: Ford and Charles, 1988.

Traction Radial Drive Axle Tires

PILOT® XDHT

Low Profile Traction, Drive Axle Highway Radial Designed for High Torque Applications, Mud and Snow Capability.

XDHT

Traction, Drive Axle Highway Radial Designed for High Torque Applications, Mud and Snow Capability.

PILOT® XDA®

Fuel Efficient Low Profile Traction, Drive Axle Highway Radial with Mud and Snow Capability.

All Wheel Position Truck Tires

XZA®

All Wheel Position Highway Rib Radial.

PILOT® XZU

Low Profile Highway Radial for Urban Applications.

PILOT® XA®

All Wheel Position Low Profile Highway Rib Radial.

All Wheel Position Truck Tires

XZZ

All Wheel Position Highway Rib Radial.

Trailer Tires

PILOT® XTA

Low Profile Highway Rib Radial Optimized for Trailer and Dolly Use.

XTA

Highway Rib Radial Optimized for Trailer and Dolly Use.

APPENDIX D

Truck Operating Tax Tables

The following tables are reproduced with the permission of the American Trucking Association. They reflect the typical federal and state taxes which would be incurred by an operator in the United States and in a particular state.

FEDERAL TAXES

Federal Highway-User Taxes
For Selected Motor Vehicles[1]/

Vehicle Type	Excise Tax	Fuel Tax	Tire Tax	Truck Use Tax	Total Federal Use Taxes
ium Weight senger Car	N/A[2]/	$52.29	N/A	N/A	$52.29
up Truck lbs.	N/A	$47.61	N/A	N/A	$47.61
le Unit Truck, 24,000 lbs. el	N/A	$468.75	$26.85	N/A	$495.60
le Tractor i-Trailer, 40,000 lbs. oline	$737.42	$1,000.05	$35.52	N/A	$1,772.99
le Tractor i-Trailer, 60,000 lbs. el	$783.64	$1,525.35	$121.26	$210.00	$2,640.25
le Tractor i-Trailer, 78,000 lbs. el	$1,319.44	$2,105.25	$163.67	$550.00	$4,138.36
le Tractor itrailer and Full er, 80,000 lbs. el	$1,449.95	$2,068.95	$172.60	$550.00	$4,241.50

e types are based on classifications found in the publication, "Road User and Property Taxes", 1987, FHWA. Sources for calculations e: "Comparison of Federal Highway Use Taxes Paid by Twelve Typical Vehicles", 1987, American Trucking Assns. and "Highway Statis-987", Federal Highway Administration.
' Not Applicable

E: American Trucking Associations, Department of Highway Policy, January 1987.

STATE TAXES[1]/

State	Annual Regis. & Wt. Fees[2]/	Diesel Fuel Tax Rate (¢/gal.)	Third Struct. Tax Rate (¢/mile)	Total Annual State Hwy-User Fees	States Ranked By Total U.S. Fees Paid
Alabama	$ 800	14.00		$2,765	43
Alaska	240	8.00		1,363	51
Arizona	1,107	17.00	8.0	9,893	1
Arkansas	1,044	12.50	2.5	4,798	12
California	1,183	14.00*		3,190	34
Colorado	37	20.50	6.0	7,714	3
Connecticut	1,391	20.00		4,198	16
Delaware	430	16.00		2,676	45
District of Columbia	709	15.50		2,884	41
Florida	967	9.70*		2,348	48
Georgia	708	10.60*		2,196	49
Hawaii	490	22.50*		3,646	27
Idaho	136	18.00	4.275	6,254	6
Illinois	2,212	19.20*		4,907	10
Indiana	1,380	27.00*		5,169	8
Iowa	1,705	22.50		4,863	11
Kansas	1,351	13.00		3,176	35
Kentucky	1,280	19.20		7,175	4
Louisiana	970	16.00		3,216	32
Maine	888	19.00		3,555	26
Maryland	1,300	16.50		3,896	23
Massachusetts	590	11.00		2,134	50
Michigan	1,316	19.00*		3,983	21
Minnesota	1,763	20.00		4,570	14
Mississippi	1,531	18.20		4,085	19
Missouri	1,726	11.00		3,272	31
Montana	1,731	20.00		4,538	15
Nebraska	1,261	16.20*		3,635	25
Nevada	498	20.00	4.25	6,705	5
New Hampshire	656	14.00		2,621	48
New Jersey	859	13.50		2,754	44
New Mexico	133	16.20	3.166	4,941	9
New York	861	17.40*	3.3	5,943	7
North Carolina	933	15.95*		3,172	36
North Dakota	1,058	17.00		3,442	30
Ohio	797	14.80	2.0	4,474	16
Oklahoma	997	13.00		2,622	42
Oregon	205	18.00	11.30	9,245	2
Pennsylvania	1152	23.40*		4,436	17
Rhode Island	440	15.00		2,545	47
South Carolina	810	18.00		3,056	38
South Dakota	1,470	16.00		3,996	20
Tennessee	1,351	15.00		3,456	29
Texas	655	15.00		2,960	39
Utah	1,171	19.00		3,838	24
Vermont	1,257	14.00		3,222	33
Virginia	1,223	19.50*		3,969	22
Washington	1,156	16.00		3,684	28
West Virginia	736	15.35*		2,890	40
Wisconsin	1,750	20.90		4,683	13
Wyoming	120	8.00	2.40	3,163	37
Average	$ 996	16.58¢	4.673¢	$4,064	

*Includes retail sales tax or other tax applied to fuel at latest available fuel price.

[1]/Figures are as of January 1, 1988 and reflect fees based on a 80,000 lb. GVW, 5-axle, tractor-semitrailer combination (15,800 lb. unladen weight for tractor and 11,500 lb. unladen weight for trailer) that consumes 14,035 gallons of fuel and travels 80,000 miles annually.

[2]/Vehicle is registered in and travels all its miles in the home state. Renewal registration is assumed. Power Unit and Trailer registration-related fees only; excludes such other fees as public utility fees, operating permit fees and ad valorem taxes.

SOURCE: American Trucking Associations, Dept. of State Laws, January 1989.

APPENDIX E

State Regulations

The following are reproduced with the permission of The American Trucking Association.

Under the Surface Transportation Assistance Act (STAA), each state is required to allow "reasonable access" to the interstate system by trucks. Each state has determined what "reasonable" is.

If an operator ventures beyond the limits set by the state, the operator may be in violation of local or state law <u>even if</u> legal on the interstate.

Page E2 is a summary of access provisions, by state, of those states which restrict access on state roads beyond the federal bridge formula.

Page E3 is a summary of those states who, by reason of "Grandfathering", do not use the federal bridge formula. The higher limits allowed by those states are set forth in this table.

For example, the federal bridge formula limits tandem axles, under 8 feet, to 34,000 pounds; at 7 feet, Colorado allows 47,000 pounds while Florida allows 44,000 pounds. These higher limits are allowed by the federal government because they were in effect before the federal limits were proposed.

Page E4 is a summary of size and weight restrictions, by state.

DETAILED STATE ACCESS PROVISIONS

The Surface Transportation Assistance Act requires states to provide "reasonable" access by 48', 102" vehicles to and from the Interstate and National Network highways. Access provisions listed below are currently in effect for states not allowing access on all state roads and highways. States will provide a map and/or listing showing the permissible routes.

The following states allow unlimited access on state highways: Arkansas, Colorado, Hawaii, Idaho, Indiana (all public roads, local restrictions may apply), Kansas (all roads/hwys), Mississippi, Montana (all roads/hwys), Nebraska, Nevada (all public roads-48'-102"-28½'), Ohio (all public roads, local restrictions may apply), South Dakota, Texas (all roads/hwys), Utah (all public roads, local restrictions may apply), Washington, Wyoming

ALABAMA
Width: All roads except county roads of less than 12' lane widths
Tractor-semitrailer: 50'-102" allowed same as width
Twin Combinations: One mile access to Interstate System, 4 lane highways and 2 lane highways additionally designated
NOTE: National Network routes not available for grandfathered trailers (53')

ALASKA
Width, tractor-semitrailer, twin combinations: 25 miles

ARIZONA
Width: Access over existing truck routes to terminals and facilities for food, fuel, repairs and rest
Tractor-semitrailer, twin combinations: All roads, depending on width

CALIFORNIA
Width: All roads except as posted
Tractor-semitrailer, twin combinations: Access restricted to ½ mile, and specified routes to terminals as authorized by state DOT and local authorities

CONNECTICUT
Width, tractor-semitrailer: All roads
Twin Combinations: Access restricted to ½ mile (beyond that, by permit via shortest practical route). Drivers must secure special driver's license

DELAWARE
Width, tractor-semitrailer, twin combinations: Interstate and all U.S. numbered routes except as posted. Access by specific route permit only

DISTRICT OF COLUMBIA
Width, tractor-semitrailer, twin combinations: Access by permit only

FLORIDA
Width: Federal system includes state roads with traffic lanes 12' or more in width unless specifically prohibited
Tractor-semitrailer, twin combinations: Access in rural areas, one mile on two-lane roads, three miles on four-lane highways, in urban areas, one mile on highways with lane widths at least 12'

GEORGIA
Width, twin combinations: One mile at specified interchanges
Tractor-semitrailer: All roads with 12' lane widths (subject to 60' overall)

ILLINOIS
Width, tractor-semitrailer, twin combinations: Access of five miles on state highways and designated local roads to points of loading and unloading and to facilities for food, fuel, repairs and rest
Weight: Access for vehicles over 73,280 lbs on local routes if posted

IOWA
Width, tractor-semitrailer, twin combinations: Access restricted to five miles and all roads and streets within cities connected to the Federal system and within the following distances of such cities, notwithstanding restrictions by local ordinances: population less than 2500, 3 miles, 2500 to 25,000, 4 miles, 25,000 to 100,000, 8 miles, 100,000 to 200,000, 8 miles, and over 200,000, 10 miles. 53'-102" vehicles permitted access by designated route to points of loading and unloading

KENTUCKY
Width, tractor-semitrailer, twin combinations: Access restricted to five miles on state-maintained highways

LOUISIANA
Width, tractor-semitrailer, twin combinations: Access restricted to three miles

MAINE
Width: All roads
Tractor-semitrailer, twin combinations: Access restricted to two miles in rural areas and ½ mile in urban areas; permit required for operations beyond, unlimited for vehicles not exceeding 38' kingpin limit

MARYLAND
Width: Shortest practical route
Tractor-semitrailer, twin combinations: Shortest practical route between a designated highway and a truck terminal, or point of origin or destination for cargo, or up to one mile to facilities for food, fuel, repairs or rest

MASSACHUSETTS
Width, tractor-semitrailer, twin combinations: Access by specific route permit to terminals upon carrier petition; twins to specific business locations greater than 5 miles by petition

MICHIGAN
Width, tractor-semitrailer, twin combinations: Access restricted to five miles

MINNESOTA
Width: All roads
Tractor-semitrailer, twin combinations: Access allowed between designated highways and facilities for food, fuel, repairs and rest, points of loading and unloading for HHG and livestock carriers "or for the purpose of providing continuity of route." Designated highways consist of the Interstate System, divided highways having four or more lanes and other state designated roads

MISSOURI
Width, tractor-semitrailer, twin combinations: Access restricted to ten miles

NEW HAMPSHIRE
Width, tractor-semitrailer: All roads with lane widths at least 12'
Twin Combinations: Access by permit only

NEW JERSEY
Twin combinations: Access up to 1 mile
Tractor-semitrailer: All roads (48' - 96" combinations), up to 2 miles (48' – 102" combinations)

NEW MEXICO
Width: All roads
Tractor-semitrailer, twin combinations: Access (and deliveries) within twenty miles of the Interstate system and designated highways

NEW YORK
Width, tractor-semitrailer, twin combinations: Access restricted to 1500' on state roads, other specified routes to be authorized by state DOT upon carrier petition

NORTH CAROLINA
Width, tractor-semitrailer, twin combinations: Access by application beyond 3 miles

NORTH DAKOTA
Width: All roads
Tractor-semitrailer, twin combinations: Access available on all state highways, vehicles over 75' in overall length access via designated state highways

OKLAHOMA
Width: No access provisions but allowed on any road having surface width of 20' or more (4-lane divided hwy)
Tractor-semitrailer: Semitrailer length restricted to 59'6"
Twin Combinations: Semitrailer or trailer length restricted to 29' off the Federal system

OREGON
Width, tractor-semitrailer, twin combinations: Access up to ½ mile from National Network, except where posted, and on designated routes (up to 48' trailer)

PENNSYLVANIA
Width: All roads of 12' lane widths
Tractor-semitrailer, twin combinations: Access to 2 10 mile, access beyond allowed with written approval of state DOT

RHODE ISLAND
Width, tractor-semitrailer: All roads
Twin Combinations: Access restricted to one mile in urban areas and one mile in rural areas on two-lane roads and three miles in rural areas on four-lane roads. Other access routes authorized by carrier permit

SOUTH CAROLINA
Tractor-semitrailer: All roads as designated
Width, twin combinations: To terminals shipper points distribution warehouses, etc., 3 miles otherwise

TENNESSEE
Width, twin combinations tractor-semitrailer: Access allowed by shortest reasonable route with state approval

VERMONT
Width: All roads
Tractor-semitrailer: Unlimited within 60' overall
Twin Combinations: Access without permit limited to ½ mile at specified exits for fuel, food, lodging, repairs and access to terminals and specific locations by permit

VIRGINIA
Width, tractor-semitrailer, twin combinations: Access restricted to shortest possible route not to exceed ½ mile

WEST VIRGINIA
Width, tractor-semitrailer, twin combinations: Access restricted to two miles including points of loading and unloading

WISCONSIN
Width: All roads except where posted
Tractor-semitrailer, twin combinations: Access not to exceed five miles including points of loading and unloading or staging or vehicle assembly facilities

LONGER/HEAVIER COMBINATIONS/TURNPIKE/TOLL ROAD OPERATIONS

The operations outlined below are authorized by rules and regulations of the state and are subject to change with little or no notice. The notations do not describe twin 28' combinations on the Interstate, but rather longer vehicles (doubles and triples) not prescribed in the Surface Transportation Assistance Act. Detailed information concerning the required permits and fees may be obtained from individual state agencies. For further information, see ATA's *Driver's Guide to Oversize/Overweight Permits*

ARIZONA — Longer doubles combinations and triple trailer combinations are allowed only on I-15, and are subject to 111,000 lbs GVW and 105' in length

COLORADO — The state allows the operation of twin 48' turnpike doubles, 48'-28' Rocky Mountain doubles, and 28' triple trailer combinations on Interstates 25, 70, 270, 76, and 225. Longer vehicle combination (LVC) permit is obtained from Department of Highways in Denver with a tractor specific annual fee. Terminal must be within 10 miles of Interstate. Weight is limited to 80,000 lbs GVW on all doubles, plus 96' for Rocky Mountain and 105' for turnpike doubles

FLORIDA — The Florida Turnpike Authority allows twin 45' trailers to operate on the turnpike, subject to 110' length and 138,271 lbs GVW limitations

IDAHO — Doubles combinations limited to 48' trailer length, 105' overall length and 105,500 lbs GVW under annual permit. Triple trailer combinations limited to 105' overall length and 105,500 lbs GVW

INDIANA — The Indiana Toll Road Commission will authorize the movement of twin 48'6" trailer combinations not exceeding 127,400 lbs GVW on the toll road. Contact the commission in Grandeau for permit information. Triple trailer combinations are allowed subject to 28' trailer length, no overall length limit, and 127,400 lbs GVW

KANSAS — The Kansas Turnpike Authority will allow twin 48' trailers subject to 119' overall length and 120,000 lbs GVW. The authority will also allow triple trailer combinations subject to the overall length and gross weight specified above

MAINE — The Maine Turnpike Authority will allow twin 28'6" trailers to operate on the turnpike. Longer combinations not allowed

MASSACHUSETTS — The Massachusetts Turnpike Authority allows twin 48' trailer combinations under an annual permit. Gross weight cannot exceed 127,400 lbs and equipment must be certified. No triple trailer combinations are allowed

MONTANA — The state will allow twin 28'6" trailer and Rocky Mountain doubles combinations up to 75' in overall length (permit required over that length). Triple trailer combinations are allowed up to 110' in length on Interstate highways

NEBRASKA — The state will allow triple trailer combinations not exceeding 105' in overall length as long as the trailers are empty and the carrier maintains $1 million in insurance. Such combinations are permitted west of Highway 80, and must originate from a staging area no more than six miles from the Interstate. Doubles combinations other than the twin 28'6" trailers are not allowed

NEVADA — The state will allow doubles combinations not exceeding 48' for the first trailer and 42' for the second trailer (heavier trailer in the lead), and triple trailer combinations subject to a 105' overall length, a 129,000 lbs GVW, and the trailer lengths noted above

NEW YORK — The New York Thruway Authority allows twin 48' turnpike doubles subject to 114' overall length, 143,000 lbs GVW, and equipment and driver certification. No triple combinations are allowed

NORTH DAKOTA — The state allows twin 48' and twin 45' trailer combinations on and off the Interstate, subject to 80,000 lbs GVW and 110' overall length on the Interstate, and 105,500 lbs GVW and 88' overall length off the Interstate. Triple trailer combinations have the same length and weight limits

OHIO — The Ohio Turnpike Authority will allow a short doubles combination no longer than 70' or turnpike doubles up to 90' without a permit. Both are subject to 127,400 lbs GVW. Combinations exceeding 90' must obtain an operating permit, which includes mileage based fees. Triple trailer combinations are not allowed

OKLAHOMA — The state allows triple 29' trailer combinations (three mile access) under a permit. Also allows Rocky Mountain and turnpike doubles on Interstate and four-lane highways (five mile access)

OREGON — Allows triple 32' or triple 28' combinations or 105' overall under either a single trip or an annual permit but trailers must be consistent in size to within 6', and gross weight cannot exceed 105,500 lbs. Also allows doubles combinations with a lead trailer no greater than 40', trailer-trailer length no greater than 68' and 105,500 lbs GVW. Both double and triple trailer combinations allowed on designated highways only

PENNSYLVANIA — The Pennsylvania Turnpike Authority will allow twin 28'8" trailers on the turnpike, subject to an overall length of 76' and 100,000 lbs GVW. Triple trailer combinations are not allowed

SOUTH DAKOTA — Allows triple 28'6" trailers subject to an overall length of 110'. Allows Rocky Mountain doubles throughout the state subject to an overall length of 81'6" and a 45' trailer length. Allows turnpike doubles on the Interstate subject to 110' overall length and 129,000 lbs GVW

UTAH — Under annual permits triple trailer combinations not exceeding 105' in overall length, truck and two trailer combinations with trailers of equal length not exceeding 95' in overall length, Rocky Mountain doubles not exceeding 98' in overall length, and twin trailer combinations not exceeding 105' in overall length may be operated on the Interstate and designated highways. Under quarterly or annual permits two unit combinations not exceeding 77' in overall length or 84,000 lbs gross weight may be operated on all highways. Also under quarterly or annual permits three unit combinations up to 92' in overall length with gross weight determined by Formula B limits may be operated on all roads. Utah also allows 129,000 lbs under permit and 63' trailers under permit (40'6" limit from kingpin to center of rear tandem axle). Autotransporters with two stinger steered trailers not exceeding 105' in overall length may obtain annual permits

WASHINGTON — The state will allow Rocky Mountain doubles with a combined trailer length of 68' up to 105,500 lbs GVW provided that if the trailer-trailer length exceeds 60', the vehicle must be operated under an annual permit. No triple trailer combinations are allowed

WYOMING — Rocky Mountain doubles with trailers not exceeding a

TABLE A ALLOWABLE LOADS
(In 1,000 lbs.)

Distance	Arizona	Colorado	Florida	Illinois			Minnesota					Missouri	New Mexico	New York	Ohio	Washington			Wyoming	D C.
				3 Axles	4 Axles	5 Axles	3 Axles	4 Axles	5 Axles	6 Axles	7 Axles					3 Axles	4 Axles	5 Axles		
4	34.0	44.0	44.0									32.0	34.3	38.0						
5	34.0	45.0	44.0									32.0	35.1	39.0						
8	34.0	46.0	44.0									32.0	35.9	40.0						
7	34.0	47.0	44.0				41.5					32.0	36.7	41.0						
6	42.0	46.0	44.0				42.0					33.2	37.4	42.0	48.0	42.0				37 0
9	42.5	49.0	48.5				43.0					34.4	38.2	43.0	48.0	42.5				38 1
10	43.5	50.0	49.4	41.0			43.5	49.0				35.6	39.0	44.0	48.0	43.5			43.5	39 1
11	44.0	51.0	50.3	42.0			44.5	49.5				36.6	39.8	45.0	48.0	44.0			45 0	40 2
12	50.0	52.0	51.3	43.0			45.0	50.0				36.0	40.8	48.0	48.8	45.0	50.0		48.0	41.3
13	50.5	53.0	52.2	44.0			46.0	51.0				39.2	41.3	47.0	49.7	45.5	50.5		50.0	42.3
14	51.5	54.0	53.1	44.5			46.5	51.5	57.0			40.4	42.1	48.0	50.8	48.5	51.5		52 0	43 4
15	52.0	55.0	54.0	45.0	50.0		47.5	52.0	57.5			41.6	42.9	49.0	51.5	47.0	52.0		54.0	44.5
16	52.5	58.0	54.9	46.0	50.5		46.0	53.0	58.0			42.8	43.7	50.0	52.4	48.0	52.5	52.5	54.0	45.6
17	53.5	57.0	55.8	47.0	51.5		49.0	53.5	59.0			44.0	44.5	51.0	53.3	48.5	53.5	53.5	54.0	46 7
16	54.0	58.0	56.8	47.5	52.0		49.5	54.0	59.5			45.2	45.2	52.0	54.2	49.5	54.0	54.0	56.0	47.8
19	54.5	59.0	57.7.	48.0	52.5		50.5	55.0	80.0			46.4	53.1	53.0	55.1	50.0	54.5	54.5	58 0	48 8
20	55.5	60.0	58.6	49.0	53.5		51.0	55.5	60.5	66.0	72.0	47.6	54.0	54.0	56.0	51.0	55 5	55.5	62.0	49 9
21	55.0	61.0	59.5	50.0	54.0		52.0	56.0	61.5	87.0	72.5	46.6	54.9	55.5	58.9	51.5	56.0	56 0	64.0	51.0
22	56.5	62.0	60.4		54.5		52.5	57.0	82.0	67.5	73.0	50.0	55.8	56.0	57.8	52.5	56.5	56.5	65.0	52.1
23	57.5	63.0	61.3		55.5		53.5	57.5	62.5	68.0	73.5	51.0	58.7	57.0	58.7	53.0	57.5	57.5	66.0	53 1
24	58.0	64.0	62.3		56.0		54.0	56.0	63.0	88.5	74.0	52.0	57.8	58.0	59.8	54.0	58.0	58 0	66.0	54.2
25	58.5	65.0	63.2		56.5			59.0	84.0	89.0	75.0	53.0	58.5	59.0	80.5	54.5	56.5	58.5	66.0	55.3
26	59.5	66.0	64.1		57.5			59.5	84.5	70.0	75.5	54.0	59.4	80.0	81.4	55.0	59.5	59.5	66.0	56 4
27	60.0	67.0	65.0		58.0			60.0	65.0	70.5	76.0	55.0	60.3	81.0	62.3	56.0	60.0	60.0	66 0	57 4
28	60.5	68.0	65.9		58.5			81.0	85.5	71.0	78.5	58.0	81.2	62.0	63.2	57.0	60.5	61.0	66 0	58 5
29	61.5	89.0	66.8		59.5			81.5	66.5	71.5	77.0	57.0	62.1	63.0	64.1	57.5	61.5	62.0	66.0	59 6
30	62.0	70.0	67.8		60.0			82.0	87.0	72.0	77.5	58.0	83.0	64.0	65.0	58.5	62.0	83.0	67.0	60.7
31	62.5	71.0	68.7		60.5			83.0	87.5	73.0	78.5	59.0	83.9	85.0	65.9	59.0	62.5	64 0	68.0	61.7
32	63.5	72.0	69.6		61.5			83.5	66.0	73.5	79.0	60.0	84.8	86.0	86.8	60.0	63.5	65.0	69 0	62.8
33	64.0	73.0	70.5		62.0			64.0	69.0	74.0	79.5	61.1	65.7	67.0	67.7		64.0	66 0	70.0	83.9
34	64.5	74.0	71.4		62.5			65.0	69.5	74.5	80.0	62.2	68.6	88.0	68.6		64.5	67.0	71.0	65.0
35	65.5	75.0	72.3		63.5			65.5	70.0	75.0		63.5	87.5	69.0	89.5		85.5	68.0	72.0	66 2
36	66.0	76.0	73.2		84.0			66.0	70.5	76.0		84.8	88.4	70.0	70.4		66.0	69.5	73.0	67.2
37	66.5	77.0						87.0	71.5	76.5		65.9	69.3	71.0	71.3		66.5	70.5	74.0	68 1
38	87.5	76.0						87.5	72.0	77.0		67.1	70.2		72.2		67.5	72.0	75 0	68 9
39	89.0	79.0						68.0	72.5	77.5		66.3	71.1		73.1		68.0	72.5	76.0	69 7
40	70.5	80.0						89.0	73.0	78.0		89.7	72.0		74.0		68.5	73.0	76.0	70.6
41	72.5	81.0						69.5	74.9	79.0		70.8	72.9		74.9		69.5	73.5	76.0	71 4
42	74.0	82.0				72.0		70.0	74.5	79.5		72.0	73.8		75.8		70.0	74.0	76.0	72.3
43	75.0	83.0				73.0		71.0	75.0	80.0		73.3	74.7		76.7		70.5	75.0	76.0	
44	75.5	84.0				73.3		71.5	75.5				75.6		77.6		71.5	75.5	76.0	
45	76.0	85.0						72.0	76.0				76.5		78.5		72.0	76.0	77.0	
46	76.5								77.0				77.4		79.4		72.5	76.5	77.4	
47	77.5								77.5				78.3		80.0		73.5	77.0	78 3	
48	78.0								78.0				79.2				74.0	78.0	79.9	
49	78 5								79.0				80.1				74.5	78.5		
50	79.0								79.5				61.0				75.5	79 0		
51	80.0								80.0				81.9				76.0	80 0		
52													62.8				76.5	80 5		
53													83.7				77.5	81.0		
54													64.6				78.0	81.5		
55													65.5				78.5	82.5		
56													88.4				79 5	83 0		
57																	80.0	83 5		
58																		84 0		
59																		85 0		
60																		85.5		
61																		86.0		

Source: ATA, 1989.

	In Feet/Inches	In Inches	Truck (Single Unit)	Semitrailer on Interstate & National Network*	Semitrailer Length off National Network*	Overall Combination Length on Other Roads	Semitrailer or Trailer on Interstate & National Network	Twin Combination Length on Other Roads	Straight Truck + Trailer	Single	Tandem	Triple	Tire Width (lbs./inch)	Type of Restriction	Interstate	Other Roads	
Alabama	13-6	102[3]	40-0	53	50/53[8]	NR[3]	28-6	NP	NP	20,000	34,000	42,000	NS	Formula B	80,000	86,000	Alabama
Alaska	14-0	—[3]	40-0	48	45	70	80[10]	75	75	20,000	38,000	42,000	650	Formula B	–	109,000	Alaska
Arizona	13-6[1]	102[3]	40-0	57-6	51/NR[10]	65[10]	28-6	65	NR[20]	20,000	34,000	42,000	NS	Formula B, Table A[31]	80,000	80,000	Arizona
Arkansas	13-6	102	40-0	53-6	53-6	NR	28	NR	60	20,000	34,000	64,000	NS	Spec. Limits, Form. B[32]	80,000	80,000	Arkansas
California	14-0	102	40-0	48/53[7]	NR[7]	65[7]	28-6	75[10]	65	20,000[30]	34,000	34,000	NS	Table B	80,000	80,000	California
Colorado	13-6[2]	102	40-0	48/NR[10]	48/NR[10]	70[10]	28	70[10]	70	20,000	36,000[30]	54,000	NS	Formula B, Table A[31]	80,000	85,000	Colorado
Connecticut	13-6	102	60-0	48	48	NR	28	NP	60	22,400	36,000	53,800	600	Formula B w/specific limits	80,000	80,000	Connecticut
Delaware	13-6	102[3]	40-0	53	NR	60	28	NP	60	20,000	34,000	42,000	NS	Formula B, Spec. Lim.[33]	80,000	80,000	Delaware
Dist. of Columbia	13-6	102[3]	40-0	48	48	55	28	NP	55	20,000[21]	34,000[21]	42,000	NS	Table A	80,000	80,000	Dist. of Columbia
Florida	13-6	102[3]	40-0[3]	48/57-6[3]	48	NR	28	NP	60	22,000	44,000	66,000	606	Form. B, Table A & Form. B.[33]	80,000	80,000	Florida
Georgia	13-6	102[3]	60-0	48	48	60	28	NP	60	20,340	34,000[30]	42,500	NS	Formula B	80,000	80,000	Georgia
Hawaii	13-6	108	40-0	48	45	60	65[10]	65	65	20,000	34,000	42,000	NS	Formula B, Spec. Lim.[33]	80,000	88,000	Hawaii
Idaho	14-0	102	40-0	48	48[7]	NR[7]	61[11]	61[11]	75	20,000	34,000	42,000	600[33]	Table B	80,000	105,500	Idaho
Illinois	13-6	102[3]	42-0	53[7]	53[7]	55[7,11]	28-6	60	60	20,000	34,000	42,000	NS	Table B, Table A[31]	80,000	73,280	Illinois
Indiana	13-6	102	36-0	53[7]	53[7]	NR[7]	28-6	NR	60	20,000	34,000	34,000	600	Formula B	80,000	80,000	Indiana
Iowa	13-6	102[3]	40-0	53	NR[7]	60[7]	28-6	65	65	20,000	34,000	42,000	NS	Formula B	80,000	80,000	Iowa
Kansas	14-0	102	42-6	57-6	57-6	NR	28-6	NR[10]	65	20,000	34,000	42,000	NS	Formula B	80,000	85,500	Kansas
Kentucky	13-6	102[3]	46-0	53	NR	57-6	28	NP	57-6	20,000	34,000	80,000	600	Formula B	80,000	80,000	Kentucky
Louisiana	13-6	102[3]	40-0	59-6[10]	60	65	30	NR[10]	70	20,000[30]	34,000[30]	42,000	650	Specific Limits	80,000	80,000	Louisiana
Maine	13-6[1]	102	45-0	48	48[7]	65[7]	28-6	P	65	20,000[30]	34,000[30]	42,000[30]	600	Formula B[33]	80,000	80,000	Maine
Maryland	13-6	102	40-0	48	48	NR	28	NP	55	20,000[30]	34,000	42,000	—	Formula B	80,000	80,000	Maryland
Massachusetts	13-6	102	36-0	48	48/48[8]	60	28	NP	60	22,400	36,000	64,000	600	Formula B	80,000	80,000	Massachusetts
Michigan	13-6	102	40-0	53[7]	50	65	28-6	59/NR[10]	59	20,000	34,000	38,000	700	Formula B	164,000[30]	164,000[30]	Michigan
Minnesota	13-6	102	40-0	48/NR[7,10]	NR[7,10]	65	28-6	NP	65	20,000	34,000	42,000[30]	600	Formula B, Table A[31]	80,000	73,280	Minnesota
Mississippi	13-6	102	40-0	53	53	NR	30	30	NR	20,000	34,000	34,000	550	Formula B	80,000	80,000	Mississippi
Missouri	13-6[2]	102[3]	40-0	53	NR	60	28	65[10]	65[10]	20,000	34,000	34,000	NS	Formula B, Table A[31]	80,000	73,280	Missouri
Montana	14-0	102	40-0	53	53	75[10]	28-6	NR	75	20,000	34,000	42,000	600[30]	Formula B	80,000	80,000	Montana
Nebraska	14-6	102	40-0	53	53	NR	65[10]	65[10]	65	20,000	34,000	42,000[30]	NS	Table B	80,000	85,000	Nebraska
Nevada	14-0	102	40-0	53/NR[10]	48/NR[10]	70[10]	28-6/NR[10]	70	70	20,000	34,000	42,000	NS	Formula B	80,000	109,000	Nevada
New Hampshire	13-6	102[3]	40-0	48	NR	NR	28	NR	60	20,000[30]	34,000[30]	34,000	600	Formula B	80,000	80,000	New Hampshire
New Jersey	13-6	102[3]	35-0	48	48	NR	28	NP	62	22,400	34,000[30]	56,400[31]	600	Formula B	80,000	80,000	New Jersey
New Mexico	13-6[2]	102	40-0	57-6	57-6	65[10]	28-6	65	65	21,600[30]	34,320	34,320	600	Table A	80,640	86,400	New Mexico
New York	13-6	96[3]	35-0	48	45[8]	60[8]	28-6	NP	60	20,000	34,000[32,33]	42,500[33]	600	Table A, Formula B[33]	80,000	80,000	New York
North Carolina	13-6	102[3]	40-0[3]	48	NR[17]	60[17]	28	NP	60	20,000	38,000	57,000	NS	Formula B	80,000	80,000	North Carolina
North Dakota	13-6	102	60-0	53[9]	NR[9]	75[9]	NR[9]	75	75	20,000	34,000	42,000	650	Formula B	80,000	105,500	North Dakota
Ohio	13-6	102	40-0	53	53	NR	28-6	NR	65	20,000	34,000	48,000	650	Table A	80,000	80,000	Ohio
Oklahoma	13-6	102[3]	45-0	59-6	59-6	NR	29	NR[10]	70	20,000	34,000	42,000	NS	Table B	80,000	80,000	Oklahoma
Oregon	14-0	102	40-0	48/NR[10]	NR	60[17]	65[10]	80[10]	75	20,000	34,000	42,000	600	Table B	80,000	80,000	Oregon
Pennsylvania	13-6	102[3,4]	40-0	48[10]/53	NR	60	28-6	NP	60	20,000	34,000	42,500	600	Formula B[33]	80,000	80,000	Pennsylvania
Rhode Island	13-6	102	40-0	48-6	48-6	NR	28	NP	NS	22,400	44,000	NS	NS	Specific Limits	80,000	80,000	Rhode Island
South Carolina	13-6	102[3]	40-0[3]	48	48	60	28-6	NP	60	20,000[30]	35,200[30]	39,600[30]	600[30]	Specific Limits, Table B[33]	80,000	80,808	South Carolina
South Dakota	13-6	102	45-0	53	53	NR[10]	81-6[14,15]	81-6[14,15]	80	20,000	34,000	42,000	600	Formula B	80,000	129,000	South Dakota
Tennessee	13-6	102[3]	40-0	50[7]	50[7]	NR	28-6	NP	65	20,000	34,000	34,000	NS	Formula B	80,000	80,000	Tennessee
Texas	13-6[2]	102	45-0	57	57	NR	28-6	NR	65	20,000	34,000	42,000	650	Table B	80,000	80,000	Texas
Utah	14-0	102	45-0	48[7]	48[7]	NR[7]	61[10]	61/NR[10]	65	20,000	34,000	42,000	NS	Table B	80,000	80,000	Utah
Vermont	13-6	102	55-0	48	45/NR[8]	60[8]	28	NP	60	22,400	36,000	38,000	600	Table B	80,000	80,000	Vermont
Virginia	13-6	102[3]	40-0	48	NR[17]	60[17]	28	NP	60	20,000	34,000	42,000	650	Table B	80,000	80,000	Virginia
Washington	14-0	102	40-0	48	48	NR	60[10]	60[10]	75	20,000	34,000	42,000	600	Table B	80,000	80,000	Washington
West Virginia	13-6[1]	102[3]	40-0	48	NR	60	28	NP	60[16]	20,000	34,000	42,500[30]	NR	Table B	80,000	80,000	West Virginia
Wisconsin	13-6	102	40-0	48/53[7]	48	60	28-6	NP	60	20,000	34,000	42,000	NS	Table B	80,000	80,000	Wisconsin
Wyoming	14-0	102	60-0	60	60	NR	60[10]	60[10]	65	20,000[30]	36,000	42,500	600[37]	Formula B, Spec. Lim.[33]	80,000	117,000	Wyoming

The Surface Transportation Assistance Act of 1982 (P.L. 97-424) required all states to adopt the following standards governing vehicle width, length and weight. All states have adopted these minimum requirements.

WIDTH Limitation of 102" (exclusive of safety devices) on the Interstate and National Network qualifying highways with lanes of 12' or more in width.

LENGTH Not less than a 48' semitrailer in a tractor semitrailer combination or a 28' semitrailer in a tractor semitrailer trailer (twin or doubles) combination on the Interstate and those classes of qualifying Federal aid primary system highways designated by the Secretary of Transportation. No overall length on either combination is allowed to be set by the state on the qualifying highways.

WEIGHT Limits of 20,000 lbs. single axle, 34,000 lbs. tandem axle and maximum gross weight of 80,000 lbs., including enforcement tolerances, on the National System of Interstate and Defense Highways. Overall maximum gross weight and axle groupings must conform to weight limitations provided by federal bridge formula (see other side for formula and chart). Reasonable access (as defined by the state currently) must be allowed to and from the Interstate to terminals and facilities for food, fuel, repairs and rest.

GENERAL FOOTNOTES

NR – Not Restricted
NP – Not Permitted
NS – Not Specified
* – Longer trailers may be allowed in some states under permit situations or through federal STAA preemption.
P – Operated by permit only

FOOTNOTES – Height

- Maine – 15' load height
- Arizona – 14' on designated highways. Colorado – 14'6" on certain highways. Iowa – 14' divisible loads permit needed. Missouri – 14' on Interstates and designated routes. New Mexico – 14' for van type trailers. Texas – 14' autocarriers. West Virginia – height may vary depending on route traveled.

FOOTNOTES – Width

- 96" on other roads and roads with less than 12' lane widths. Missouri – 102" on all designated routes plus access, otherwise 96". South Carolina – 10' lane widths (permit required).
- New Jersey – 102" on all roads with 11' lane widths, divided highways. Oklahoma – 96" on all roads with less than 20' surface width.

FOOTNOTES – Length

- Two axle truck 36'
- Alabama – 53' trailer/60' overall limit, 60' trailer/NR overall. New York – allows 48' trailer/60' overall length on other highways. 48' trailer 55' overall length on other roads. Vermont – longer than 45' trailer, than 60' overall and special permission necessary.
- Internal measurement generally from kingpin to center of rear axle also governs length limit. California – 40' (over 48' trailer). Idaho – 39' (Illinois) – 40' (over 48' trailer). Indiana – 40'6" (over 48.5' trailer). Iowa – 40'. Maine (measured on trailers over 48' from rear tractor axle to rear trailer axle) – 38'. Michigan – 40'6" (designated highways). Minnesota – 41' (over 48' trailer, overall length also cannot exceed 65'). Tennessee (measured from kingpin to rear of trailer) – 60'. Wisconsin – 41' measure applies to 53' trailers.
- Massachusetts – 48' by terminal access annual permit (fee charged for annual permit).
- North Dakota – trailers longer than 53' – 95' overall limit; longer than 75' allowed on designated system.
- Trailer length may exceed limit as long as overall length is not exceeded; permit may be necessary.
- Measured as wheelbase between steering axle and rearmost axle on certain state highways, otherwise 65' measured from bumper to bumper on other roads.
- Measured from front of first trailer to rear of second trailer including connecting device. Idaho – 75' overall if tri-connector; tri exceeds 61'. Oregon – 60' overall trailer limit on group one highway only; 68' overall trailer limit allowed on designated routes only. South Dakota – maximum trailer length 65'. Utah – no overall length limit if trailing units measure 61' or less. Wyoming – 48' semitrailer, 40' trailer limit.
- Hawaii – doubles combination allowed of 65' overall length.
- South Dakota – sum of trailers plus tow bar (tow bar not to exceed 10').
- Allowed on specified state highways of 65' but state sets 65' limit on certain other highways.
- Semitrailer and/or trailer limits apply. California – 28'6". Kansas – 28'6". Oklahoma – 29'. South Dakota – 48' semitrailer, 28'6" trailer. Wyoming – 48' semitrailer, 40' trailer allowed.
- Oregon – 60' includes unlimited trailer length, but permitted on group one highways only. North Carolina and Virginia – unlimited trailer length, 60' overall, state routes only.
- Overall length limit does not apply when trailer length limit is not exceeded.
- State may further restrict limits on certain roads.
- Single unit limits govern.

FOOTNOTES – Weight

- Higher limits allowed on all highways except Interstate.
- Higher limits allowed off Interstate (including tolerance applicable).
- Requires 8' or more of spacing.
- Requires 8' or more of spacing.
- Requires 8'0" or more of spacing.
- Vehicles manufactured before 7/1/87 may carry 800 lbs.
- Excludes steer axle from limit. Wyoming – 750 lbs. steer axle.
- Specific limits apply off Interstate.
- Formula B applies over 73,280 lbs. gross weight.
- Formula B applies over 73,271 lbs. gross weight.
- Table A applies off Interstate, primary highways and certain defined routes; check with state.
- Formula B applies over 71,000 lbs. gross weight, under 71,000 A.
- Table B applies over 70,195 lbs. gross weight on Interstate.
- Maximum allowable axle weight limited to 13,000 lbs. with one lb. tandem axle and on 10,000 lb. steering axle.
- Higher weight limits apply for vehicles over 73,280 lbs. GVW Interstate.
- Steer axle limits: California – 12,500. New Mexico – 10,000.

APPENDIX F

Survey Data

The Vehicle Management Maintenance Conference (VMMC) is targeted toward those parties responsible for the management and maintenance of fleets of trucks and related components. The thrust of the conference is more toward effective maintenance of equipment rather then operations. None the less, it was felt that the firms, agencies and individuals represented would be a valuable source of information on operating procedures.

The survey data was broken into three groups for analysis; those respondents from 1988 with over 100 vehicles in their fleets, those 1988 respondents with under 100 vehicles in their fleets, and 1989 data. (The 1989 respondents included only one with over 100 vehicles).

Included in this appendix are copies of the survey forms used in 1988 and 1989 and a summary of the responses.

This report did not utilize all of the questions asked on the survey; some of the questions were posed from an industry perspective for industry use or for use at a later date. The data utilized is summarized here.

37th ANNUAL VEHICLE MAINTENANCE MANAGEMENT CONFERENCE
THE UNIVERSITY OF WASHINGTON
Seattle, Washington
March 21-24, 1988

The representation of a large segment of heavy vehicle users at this conference provides a unique opportunity to obtain data that will help in developing a better profile of the service environment and the equipment in use. This data is of general interest to the heavy vehicle manufacturer and user communities as well as to those in the highway design and transportation communities. The results of this survey will be made available to all interested parties. Your cooperation in taking the time to complete the survey is greatly appreciated.

***

Company Name:

Position with Company:

Location of Company (City and/or State):

Please provide your name and address if you would like a summary of the survey results:

Name: ________________________________ Phone no. ____________

Address: ______________________ ________________ __________
Street name and number   City and State   Zip Code

Please respond only to those questions that you feel most comfortable in answering.

***

Please identify your typical operating configuration:
(If more than one, please indicate percentage of each - for example, 70% tractor-semitrailer and 30% doubles)

___ Straight Truck (no trailers)
___ Truck - Trailer
___ Tractor-Semitrailer
___ Doubles
___ B-train or C-train
___ Other (please specify) ____________________________

Type of Power Unit:
(If more than one, please indicate percentage of each)

___ Class 8 Tractors/Trucks (33,001 lb and over)
___ Class 7 Tractors/Trucks (26,001 lb - 33,000 lb)
___ Class 6 or smaller Trucks (less than 26,000 lb)
___ Buses
___ Other (please specify) ____________________________

How many vehicles are in your fleet ? ____________
How old is your oldest vehicle ? ________________
How new is your newest vehicle ? ________________

Type of Trailers (if applicable):
___ Van - Length (ft) ________ , Width (in) _______
___ Flatbed - Length (ft) ______ , Width (in) _______
___ Tanker
___ Dump
___ Auto Carrier
___ Other (please specify) ________________________________

How many trailers are in your fleet ? ______________
How old is your oldest trailer ? ____________________
How new is your newest trailer ? ____________________

Type of Dolly used (if applicable):
___ Fixed Dolly (integrated part of trailer design)
___ A-type Converter Dolly (single drawbar)
___ B-type Converter Dolly (double drawbar)

How would you describe your typical cargo (e.g., household goods, perishable food, fuel, automobiles, etc.) ? ______________________
____

Do your vehicles operate:
___ Cross Country
___ Regional Line Haul (e.g., West Coast, Eastern Seaboard, etc)
___ Local Line Haul

Do your vehicles operate:
___ Primarily on Interstates and freeways
___ Primarily in rural areas (secondary roads)
___ Primarily in urban and city areas

Do your vehicles typically:
___ Cube out (limited by volume)
___ Gross out (limited by weight)
___ neither

What is your typical operating weight (GCW) ? ________________

How much time does your vehicle operate bobtail or empty ?
___ 0 - 10%
___ 10 - 20%
___ 20 - 30%
___ more than 30%

How many hours per day are your vehicles in operation ? ______
How many miles per year does each vehicle average ? ____________

Are there any roads on your operating route that you consider to be exceptionally rough or badly deteriorated (please identify - for example "I-95 between New York and Washington D.C.") ? _____
____
____

Are there any roads on your operating route that you consider to be exceptionally smooth or "good riding" (please identify - for example, "I-5 between Portland and Seattle") ? ____________________

____

____

What is your typical tractor/truck configuration ?

___ 4x2 (2 axles total, 1 drive axle)
___ 6x4 (3 axles total, 2 drive axles)
___ 6x2 (3 axles total, 1 drive axle)
___ Other (please specify) ______________________

Do your trailers typically have:

___ A single axle
___ Tandem axles
___ Tridem axles
___ Tandem axles and a lift axle
___ Other (please specify) _______________________

What is your typical engine horsepower ? ________________________

Why did you select that horsepower ?

___ Fuel economy
___ Maintain speed on grades
___ Required for the operation
___ Other (please specify) _______________________________________

Do you typically specify any type of engine or driveline retarder system (for example, "Jake brake") ________________________________

In the future, as antilock brake systems become available, will you be specifying ABS for your tractor/truck (___yes ___no) or your trailers (___ yes ___ no).

What type of tires do you most commonly use ?

___ Bias ply
___ Radial
___ Low profile radial
___ Super-single radial

What is your normal inflation pressure (psi) ? _____________
How often do you check inflation pressure ? ________________

As you need to replace tires, will you

___ Use the same type of tire
___ Change to Bias ply
___ Change to Radial ply
___ Change to Low Profile Radial Ply
___ Change to Super-single radials

What is your primary reason for choosing a certain type of tire ?
___ Cost
___ Fuel Economy
___ Tread wear
___ Ride
___ Name brand preference
___ Other (please specify) ______________________

Do you use any special procedure when mounting your tires (for example, "match mounting" or "clocking" on a dual set, where you line up high and low spots) ? If so, please specify. ___________
____
____

What type of wheels do you use on your tractor ?
___ Aluminum
___ Steel disc wheels
___ Steel spoke wheels
___ Other

What type of wheels do you use on your trailer ?
___ Aluminum
___ Steel disc wheels
___ Steel spoke wheels
___ Other

Do you balance your wheels and tires ? ________________
Which ones ? ______________________________
How often ? _______________________________

What type of suspension do you have on your tractor/truck drive axle(s) ?
___ Walking Beam
___ 4-spring or leaf spring
___ Air
___ Torsion Bar
___ Other (please specify) ______________________

What type of suspension do you have on your trailers ?
___ Walking Beam
___ 4-spring or leaf spring
___ Air
___ Other (please specify) ______________________

Do you typically use shock absorbers on any of your suspensions ?
Which suspension(s) ? ____________________________________

Is there a primary reason for your selection of one type of suspension over another - please specify (e.g., cost, weight, ride, etc.) ? ____
____

In order of importance, are there any factors that you believe contribute to improving or degrading vehicle ride ?
1.____
2.____
3.____

In order of importance, are there any general areas that you believe need improvement with regard to vehicle maintenance ?
1.____
2.____
3.____

What is the single most important aspect about your truck where you feel improvement needs to be made ? ____________________
____
____

Thank you for your assistance in gathering this information !

38TH ANNUAL VEHICLE MAINTENANCE MANAGEMENT CONFERENCE
THE UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON
MARCH 20-23, 1989

e representation of a large segment of vehicle users at this conference provides a unique portunity to obtain data that will help in developing a better profile of the service vironment and the equipment in use. This data is of general interest to the heavy vehicle nufacturer and user communities as well as to those in the highway design and nsportation communities. The results of this survey will be made available to all erested parties. Some of the questions are repeats from the survey last year. A summary both the 1988 and 1989 surveys will be sent to you if you provide your mailing address low. Your cooperation in taking the time to complete the survey is appreciated.

y information you provide will remain confidential (i.e. neither you or your company or ency will be specifically identified in the final report).

• • • • • • •

mpany Name:____________________

sition with Company:____________________

cation of Company (City and/or State):____________________

ase provide your name and address if you would like a summary of the survey results:

me: ____________________ Phone Number: ____________

ldress: ____________________ ____________________ ____________
Street Name and Number City and State Zip Code

ase respond to those questions that you feel comfortable in answering.

• • • • • • •

Please identify your typical operating configuration (if more than one, please indicate percentage of each - for example, 70% tractor-semitrailer and 30% doubles):____________________

__ Straight truck (no trailers)
__ Truck-trailer
__ Tractor-semitrailer
__ Doubles
__ B-train or C-train
__ Other (please specify)____________________

How many vehicles are in your fleet? ______
What is the average age of the vehicles in your fleet? ______
How old is your oldest vehicle? ______
How new is your newest vehicle? ______

3. Type of trailers (if applicable):

_____ Van Length (ft) _________, Width (in) _________

_____ Flatbed Length (ft) _________, Width (in) _________

_____ Tanker

_____ Dump

_____ Auto carrier

_____ Other (please specify)______________________________

4. How many trailers are in your fleet? ______

What is the average age of the trailers in your fleet? ______

How old is your oldest trailer? ______

How new is your newest trailer? ______

5. Do your vehicles operate:

_____ Cross country

_____ Regional line haul (e.g. West Coast, Eastern Seaboard, etc.)

_____ Local line haul

6. Do your vehicles operate:

_____ Primarily on interstates and freeways

_____ Primarily in rural areas (secondary roads)

_____ Primarily in urban and city areas

7. Do your vehicles typically:

_____ Cube out (limited by volume)

_____ Gross out (limited by weight)

_____ Neither

8. What is your typical operating weight (GCW)?______________________

What is your maximum operating weight?______________________

9. How much time does your vehicle operate bobtail or empty?

_____ 0-10%

_____ 10-20%

_____ 20-30%

_____ more than 30%

10. How many hours per day are your vehicles in operation?______________

How many miles per year does each vehicle average?______________

11. What is your typical tractor/truck configuration?

_____ 4x2 (2 axles total, 1 drive axle)

_____ 6x4 (3 axles total, 2 drive axles)

_____ 6x2 (3 axles total, 1 drive axle)

_____ Other (please specify)______________________________

12. What is the typical tire size for (e.g. 12.5 x 22.5)?:

(a) Tractor steering axle ______________________

(b) Tractor drive axle______________________

(c) Trailer axles______________________

13. Do your trailers typically have:

_____ A single axle

_____ Tandem axles

_____ Tridem axles

_____ Tandem axles and a lift axle

_____ Other (please specify)______________________________

14. What type of suspension do you have on your tractor/truck drive axle(s)?
_____ Walking beam
_____ 4-spring or leaf spring
_____ Air
_____ Torsion bar
_____ Other (please specify)____

15. What type of suspension do you have on your trailers?
_____ Walking beam
_____ 4-spring or leaf spring
_____ Air
_____ Other (please specify)____

16. Do you typically use shock absorbers on any of your suspensions?
_____ yes _____ no
Which suspensions?____

17. Is there a primary reason for your selection of one type of suspension over another? Please specify (e.g., cost, weight, ride, etc.)________________________________
____

18. Do you prefer to drive over portland cement concrete or asphalt surfaced pavements?____
Why? _____ Ride comfort _____ Road traction _____ Other

19. If you are familiar with a road and know a rough patch is coming up, do you:
_____ Speed up? _____ Slow down? _____ Maintain speed?

20. In your opinion, does your truck ride "smoother" at highway speeds (55-60 mph) or at lower (30 mph) speeds?
_____ 55-60 mph _____ 30 mph

21. Is ride affected by your load? That is, does your ride differ, at the same speed on the same road, depending on your load?
_____ Yes _____ No

22. In general, do you ride smoother when you are loaded or when you are bobtail?
_____ Loaded _____ Empty

23. What type of tires do you most commonly use:
_____ Bias ply
_____ Radial
_____ Low profile radial
_____ Super-single radial

24. Have you driven both bias and radial tires?
_____ yes _____ no

25. In your opinion, is their a difference in the way that bias belted tires track from radials? Which track is better?
_____ Bias
_____ Radial
_____ No difference
_____ No opinion

26. How often do you have your tire alignment checked?
_____ Months ______ Miles ______ When I notice a problem

27. Do they usually need aligning when you have them checked?
_____ yes _____ no

28. What is your normal tire inflation pressure (psi) for:
Steering axle? _______________
Drive axle? _______________
Trailer axles? _______________

29. When do you check your tire inflation pressure?
_____ Every morning _____ At fuel up _____ Weekly
Do you check inflation when your tires are cold or hot? _________
Do you add air to your tires when they are hot?
_____ yes _____ no

30. Do you keep your tires inflated to the maximum pressure recommended for that tire?
_____ yes _____ no

31. Have you noticed if ride is affected by tire pressure?
_____ yes _____ no
Does over or under inflation affect the ride and/or the handling?
Ride: _____ yes _____ no
How?____
Handling: _____ yes _____ no
How?____

32. As a rule, do you get the rated mileage from your tires?
_____ yes _____ no

Why do you think you do or don't?_______________________________

33. As you need to replace tires, will you:
_____ Use the same type of tire?
_____ Change to bias play?
_____ Change to radial ply?
_____ Change to low-profile radial ply?
_____ Change to super-single radials?

34. What is your primary reason for choosing a certain type of tire?:
_____ Cost
_____ Fuel economy
_____ Tread wear
_____ Ride
_____ Name brand preference
_____ Other (please specify)_______________________________

35. Do you balance your wheels and tires?
_____ yes _____ no
Which ones?_______________________________
How often?_______________________________

Mailing address: Joe P. Mahoney
Department of Civil Engineering
University of Washington
121 More Hall, FX-10
Seattle, WA 98195

(1) Please identify your typical operating configuration:

	Truck	Trck.Trl.	Semi	Other
1988 <100:	14	11	15	6
1988 >100:	19	1	3	7
1989 :	7	5	7	5

(Number of Responses)

(2) Do your vehicles operate mostly:

	Cross Country	Regional	Local Line
1988 <100:	1	5	23
1988 >100:	1	3	15
1989 :	4	7	19

(3) Do your vehicles operate primarily on:

	Interstate	Rural	Urban	roads?
1988 <100:	8	12	13	
1988 >100:	6	8	11	
1989 :	9	10	6	

(4) Are your vehicles typically limited by:

	Weight (gross out)	Volume (cube out)	Neither
1988 <100:	20	6	4
1988 >100:	16	6	4
1989 :	18	1	5

(5) How much time does your vehicle operate empty?

	0-10%	10-20%	20-30%	>30%
1988 <100:	9	1	6	10
1988 >100:	9	5	5	8
1989 :	9	3	5	6

(6) How many hours per day are your vehicles in operation?

	1-8	8-12	12-16	16-24
1988<100:	8	7	1	10
1988>100:				
1989 :	6	4	0	9

(7) What type of suspension do you have on your tractor drive axle?

	Walking Beam	Leaf Spring	Air	Other
1988<100:	12	21	9	0
1988>100:	22	14	3	5
1989 :	10	8	7	2

(8) What type of suspension do you have on your trailer(s)?

	Walking Beam	Leaf Spring	Air	Other
1988<100:	2	20	2	0
1988>100:	13	17	2	0
1989 :	5	15	4	0

(9) Is their a primary reason why you chose the suspension type you did?

	Ride	Cost	Serviceability	Durability	Other
1988<100:					
1988>100:					
1989 :	5	3	4	3	4

(10) What type of tires do you most commonly use:
Note: Radial numbers <u>include</u> LP and SS numbers.

	Bias	Radial	Low Profile Radial	Super-Single
1988<100:	2	33	8	1
1988>100:	5	21	6	1
1989 :	1	24	5	1

(11) As you need to replace tires, will you:

	Keep the same	Change to: Bias	Radial	LP	SS
1988<100:	32	0	0	0	0
1988>100:	21	0	6	3	1
1989 :	18	0	1	2	1

(12) Have you driven both bias and radial tires:

	Yes	No
1989 ONLY:	19	4

In your opinion, which track better:

	Bias	Radial	No difference	No opinion
1989 ONLY:	1	13	2	6

(13) Do you prefer to drive over portland cement concrete or asphalt surfaced pavements? Why?

	Portland Cement	Asphalt
1989 ONLY:	2	17

	Ride Comfort	Road Traction	Other
1989 ONLY:	12	6	1

(14) In your opinion, does your truck ride "smoother" at highway speeds (55-60 mph) or at lower (30 mph) speeds?

	55 - 60 mph	30 mph
1989 ONLY:	12	5

(15) Is ride affected by load? That is, does your ride differ, at the same speed on the same road, depending on your load?

	YES	NO
1989 ONLY:	18	2

(16) In general, do you ride smoother when you are loaded or when you are bobtail (empty)?

	Loaded	Empty
1989 ONLY:	20	1

(17) How often do you have your tire alignment checked?

	No. of Months	Miles	When I notice a problem
1989 ONLY:	3	0	20

(18) Do they usually need aligning when you have them checked?

	YES	NO
1989 ONLY:	17	5

(19) When do you check your tire inflation pressure?

	Daily	At Fuel Up	Weekly
1989 ONLY:	4	1	11

Do you check inflation when your tires are cold or hot?

Cold	Hot
21	1

Do you add air to your tires when they are hot?

YES	No
4	17

(20) Do you keep your tires inflated to the maximum pressure recomended for that tire?

	YES	NO
1989 ONLY:	9	12

(21) Have you noticed if ride is affected by tire pressure? How?
1989 ONLY: 12 responses that over inflation yields a hard ride, under inflation a soft ride. Also, 10 responses that underinflation is harder to steer then proper or over inflated.

(22) As a rule, do you get the rated mileage from your tires?

	YES	NO
1989 ONLY:	9	11

Why or Why not?
1989 ONLY: 9 responses cited hard use and poor drivers habits, while 7 cited good maintenance and proper tire pressure.

APPENDIX G

Washington State Patrol
Weight Stations

Provided in this appendix are summaries of fines collected by the patrol for commercial vehicle weight and safety violations in 1987 and 1988.

Additionally, published guidance available to the public hauler on dimensional and weight limits in Washington State for trucks and trailers is reproduced.

	NUMBER VEHS WEIGHED	NUMBER HOURS OPRTD.	NUMBER UNITS OVER LEGAL	VERBAL WARNS	ARRESTS	WRTTN WARNS	NO.OF AXLES OVER LEGAL	VERBAL WARNS	ARRESTS	WRTTN WARNS	NO.OF TIRES OVER LEGAL
YEAR OF 1987	1,456,795	50,344	2,432	53	2,426	3	12,896	67	12,812	17	134

ANNUAL WEIGHING OPERATION REPORT # 2 - STATEWIDE -

	NO. VEHS OVER LIC.	OVER HT.	OVER WDTH	OVER LNTH	DEFECT EQUIP	OVER PERMIT	OTHER	VERBAL WARNS	WRTTN WARNS	ARRESTS	EXCESS WEIGHT FINES IN $$$	NO. OF VEHS TO INC LIC.	AMOUNT OF LIC INC IN $$$$$$
YEAR OF 1987	1,082	1,446	709	923	62,718	1,381	499,041	24,258	33,119	10,882	$2,097,192	5,837	$347,121

ANNUAL WEIGHING OPERATION REPORT # 1 - STATEWIDE -

	NUMBER VEHS WEIGHED	NUMBER HOURS OPRTD.	NUMBER UNITS OVER LEGAL	VERBAL WARNS	ARRESTS	WRTTN WARNS	NO.OF AXLES OVER LEGAL	VERBAL WARNS	ARRESTS	WRTTN WARNS	NO.OF TIRES OVER LEGAL
YEAR OF 1988	1,676,953	73,191	3,384	56	3,325	3	16,108	110	15,943	55	305

ANNUAL WEIGHING OPERATION REPORT # 2 - STATEWIDE -

	NO. VEHS OVER LIC.	OVER HT.	OVER WDTH	OVER LNTH	DEFECT EQUIP	OVER PERMIT	OTHER	VERBAL WARNS	WRTTN WARNS	ARRESTS	EXCESS WEIGHT FINES IN $$$	NO. OF VEHS TO INC LIC.	AMOUNT OF LIC INC IN $$$$$$
YEAR OF 1988	1,322	1,599	1,000	905	76,815	1,400	583,834	29,401	41,812	11,828	$2,611,810	2,694	$434,742

Outside Width (46.44.010)
Eight feet, six inches (102 inches) inclusive of load for all vehicles

Tolerances:

1. Rearview mirror - 5 inches
2. Rubber fenders - 2 inches
3. Tires (due to expansion) - 2 inches
4. Safety appliances (clearance lights, rub rails, binder chains) - 2 inches
5. Appurtenances (door handles, door hinges, and turning signal brackets) - 2 inches

Maximum Height (46.44.020)
14 feet

Except:

1. Authorized emergency vehicle or repair equipment of a public utility engaged in reasonably necessary operations.

Maximum Length (46.44.030)
Single vehicle - 40 feet with or without load

Except:

1. The permanent structure of a single vehicle in combination not to exceed 48 feet; 56 feet with special motor vehicle permit.

   Exception: Refrigeration units placed on the front of van trailers

Combination of vehicles:

1. The overall length of any combination consisting of a *stinger steered tractor and semitrailer shall not exceed 65 feet without load, and 70 feet with load.

2. The overall length of combination of vehicles consisting of a truck and trailer shall not exceed 75 feet with or without load.

3. The overall length of a combination consisting of a tractor and semi-trailer and full trailer or tractor and semitrailer and semitrailer (B Train), the trailing units shall not exceed 60 feet, including the space between them; 68 feet with a special motor vehicle permit.

4. These length limitations shall not apply to vehicles transporting poles, pipes, machinery, or other objects of a structural nature that cannot be dismembered, and operated by a public utility when required for emergency repairs of public service facilities or properties.

*Stinger steered shall mean a tractor and semitrailer combination, which has the coupling connecting the semitrailer to the tractor located to the rear of the center line of the rear axle of the tractor.

Maximum Length of Protrusions (46.44.034)

1. Front - 3 feet
2. Rear - 15 feet beyond last axle

Combination Limits - Two Vehicles (46.44.036)

1. Exceptions: (46.44.037)

   a. Truck tractor, semitrailer, and trailer in combination.

   b. Truck tractor, semitrailer, and semitrailer in combination (B Train).

      (1) The converter gear (dolly) may be pulled behind a tractor and semitrailer in lieu of a full trailer.

   c. Three trucks or three truck tractors in double saddle-mount position.

Gross Weights - Tire

1. 600 pounds per inch width (46.44.042)

Excess Weight - Logging Trucks Operating on a Permit (Log Tolerance) (46.44.047)

1. Only the three-axle tractor and two-axle pole trailer are allowed to have the permit and are valid only on state primary and secondary highways authorized by the State Department of Transportation.

   a. A map is issued showing the approved routes.

2. An additional six feet of wheelbase is given if the combination is 37 feet or more between the first and last axles.

3. 1,600 pounds tolerance on dual axles.

4. 6,800 pounds tolerance on the combination.

5. Permit may be transferred ($5 fee).

6. Cities and counties may issue a "County Log Tolerance" permit for county roads.

   a. May charge a $5 fee.

   b. Shall designate the routes to be used.

   c. Issued on a yearly basis, expiring March 31 of each year.

   d. Any person, firm, or corporation using any city street or county road for the purpose of transporting logs with weights authorized by the state highway log tolerance permits, to reach a state highway route, without first obtaining a city or county log tolerance permit when required by the city or county shall be subject to the excess weight penalties.

Special Permits for Oversize or Overweight Vehicles (46.44.090)

1. Issued by Department of Transportation for state highways -- by local authorities with respect to the public highways under their jurisdiction.

Gross Weight Limits of Special Permits (46.44.091)

1. 22,000 pounds on a single axle.
2. 43,000 pounds on any group of axles more than 3 feet, 6 inches apart and less than 7 feet apart.
3. Weight limits may be exceeded on highways designated for greater weight.
4. Construction equipment may exceed the above with large pneumatic tires.

Special Permit Width Limits (46.44.092)

1. 14 feet on a two-lane highway.
2. 32 feet on a multiple-lane highway: Except multiple-lane highways with physical barrier serving as a median divider not in excess of 20 feet.
3. Exceptions:
   a. May be exceeded on highways designed and constructed for greater widths.
   b. May be rescinded during an emergency.
   c. 16 feet on a two-lane highway during daylight hours when the weight does not exceed 45,000 pounds.
   d. Buildings in excess of 14 feet may be moved not to exceed five miles.

Oversize Permits - Fees (46.44.0941)

1. Annual permit for 75 feet in length - $60.
   a. Permits are not restricted to hours or days.

Gross Weights (46.44.041)

1. Single axle - 20,000 pounds
2. Two-axle garbage trucks may be issued an additional tonnage permit authorizing an additional 6,000 pounds on the rear axle. Three-axle garbage trucks may be issued a permit authorizing an additional 8,000 pounds on the rear tandem axles. The fee is $30 per thousand pounds per year. The permit is not valid on interstate highways (RCW 46.44.095), and tire size limits apply (RCW 46.44.042).
3. Tandem axles - 34,000 pounds
   a. Axles spaced less than 7 feet must oscillate.

4. Three-axle vehicle - 40,000 pounds

   a. Weight in excess of 40,000 pounds, allowed by additional tonnage permit, determined by tire size and wheelbase table.

5. Vehicle combinations - 80,000 pounds

   a. Weight in excess of 80,000 pounds, allowed by additional tonnage permit, determined by tire size and wheelbase table, using overall and internal spacing.

<u>Wheelbase Table</u> (46.44.041)

1. Overall measurement is from the center of the front axle on a vehicle or combination of vehicles to the center of the last axle on vehicles or combinations of vehicles.

2. Internal measurement will include groups of axles and groups of two consecutive sets of tandem axles.

   a. Tandem axles will not be split when measuring internal spacing.

3. Minimum wheelbase - 3 feet, 6 inches; except axles spaced less than 3 feet, 6 inches, may not exceed the maximum weight allowed for a single axle (46.44.050).

4. When inches are involved in wheelbase measurements, under 6 take lower, 6 inches or over, take the higher weight.

5. Steering axle weights are determined by tire size (46.44.042).

6. <u>No enforcement tolerance will be allowed</u>.

7. To determine license gross weight and additional tonnage weight, follow the examples of overall and internal measurements. Apply the total number of axles in the overall or internal measurement and apply this to the appropriate columns on the table for gross weights.

8. Establishes a grandfather provision for vehicle or combination of vehicles in operation on January 4, 1975, to operate with weights on two consecutive sets of dual axles in effect by law on that date. This provision will allow 32,000 pounds on a tandem axle and a combined gross weight of 73,280 pounds for certain combinations.

   Combinations operating under the grandfather provision will be required to purchase a license gross weight tonnage of 74,000 pounds. A five-axle combination with a minimum overall wheelbase measurement of 44 feet, 6 inches would be allowed 73,280 pounds. Combinations with less than 44 feet, 6 inch wheelbase; their weights will be determined by the enclosed vehicle loading chart. As in the past, we will not measure internal wheelbase on vehicles operating within the weights allowed by the grandfather provision. No tolerance will be allowed over these weights.

<u>Additional Tonnage Permits</u> (46.44.095)

1. Issued by the Department of Transportation.

2. Permits are issued annually, with fees reduced by 1/12, or monthly instead of quarterly ($37.50 per thousand pounds).

   a. Permits may be transferred - fee $5.

   b. Seasonal vehicles may purchase permits quarterly. Must purchase a minimum of 6,000 pounds.

3. Temporary additional tonnage permits may be purchased for a minimum of five days at $1 per day for each 2,000 pounds.

4. Violated permits to be sent to the Department of Transportation upon third conviction.

<u>Additional Tonnage Permits - Cities and Counties</u> (46.44.0941)

1. Cities and counties may issue permits for operation on roads or streets under their jurisdiction.

2. Allowed on state roads by endorsement.

<u>Mandatory Fines for Overloading</u> (New Section--Chapter 46.44)

1. Penalties apply to tires (46.44.042), log tolerance permits (46.44.047), special motor vehicle permits (46.44.090 and 46.44.091), additional tonnage permits, axles, wheelbase, vehicles and combinations of vehicles (46.44.095), failure to obtain, display, or misrepresentation of permits (46.44.090 and 46.44.095).

2. Violation is a misdemeanor and is punishable as follows:

   a. Basic fine:

      (1) First violation - not less than $50.

      (2) Second violation - not less than $75. In addition, the court may suspend the license registration.

      (3) Third violation - not less than $100. In addition, the court shall suspend the license registration.

      (4) For license registration suspension purposes, first, second, and third violations are within any 12-month period.

      (5) In no case may the basic fine be suspended.

   b. Poundage penalty (in addition to basic fine):

      (1) Three cents per pound, provided that upon the first violation within a calendar year, the court may suspend 500 pounds on each axle, up to a maximum of 2,000 pounds on any combination of vehicles.

   c. For license suspension purposes, bail forfeitures are given the same effect as convictions.

d. Convictions are figured on a calendar year and must be on the same vehicle or combination of vehicles.

e. Penalties for violation of a posted limitation (winter restrictions):

(1) First violation - not less than $150.

(2) Second and subsequent violations - not less than $150, and, in addition, the court shall suspend the license registration for not less than 30 days.

f. Vehicles or combinations of vehicles of which the owner or operator represent as being disabled or otherwise unable to submit to immediate weighing will be sealed or marked. Removal of the seals, markings, or any part of the load prior to weighing will be punishable by a fine of not less than $500 and suspension of the license registration for not less than 30 days.

<u>Weighing and Lightening</u>

1. May require the operator to stop and submit to being weighed by portable scales or directed to the nearest public scales.

2. May require the load to be reduced to legal limits.

<u>Liability for Overloading</u> (46.44.120)

1. Owner, operator, and any person knowingly and intentionally participating in creating any unlawful condition of use shall also be subject to the penalties provided in this chapter.

<u>Overloading Licensed Capacity - Additional License</u> (46.16.140)

1. It is a misdemeanor to operate a vehicle in excess of the licensed gross weight.

a. Any person who operates a vehicle with a gross weight in excess of the licensed gross weight shall be deemed to have established a new gross weight, and, in addition to any other penalties, shall be required to purchase a new tonnage license covering the new maximum gross weight.

(1) Failure to secure such new license shall be a misdemeanor.

(2) No such person shall be permitted or required to purchase additional gross weight which would exceed the gross weight allowed by law -- increasing beyond the legal limits of tires or axles or vehicles.

<u>Overloading Licensed Capacity--Penalties</u> (46.16.145)

1. Establishes statutory fines and penalties for operating vehicles in excess of the licensed gross weight.

a. First conviction $25 to $50 fine.

b. Second conviction $50 to $100 fine, and the court may suspend the registration.

c. Third conviction $100 to $200 fine, and the court shall suspend the registration for not less than 30 days.

Movement of Farm Implements (46.44.130)

Farm implements of less than 45,000 pounds gross weight and a total outside width of less than 20 feet may move over state highways while patrolled, flagged, lighted, signed, and at a time of day in accordance to rules to be adopted by the Department of Transportation under terms of a special permit to be issued by the Department of Transportation for a quarterly or annual period.

WASHINGTON STATE TRANSPORTATION COMMISSION
DEPARTMENT OF TRANSPORTATION

VEHICLE WEIGHT TABLE

Section 46.44.041

As Last Amended By SB No. 3120, 1985 Session

...ehicle or combination of vehicles shall operate upon the public highways of this state with a gross load on any single axle in excess of twenty thousand pounds, or ... any group of axles in excess of that set forth in the following table, except that two consecutive sets of tandem axles may carry a gross load of thirty-fou... ...sand pounds each, if the overall distance between the first and last axles of such consecutive sets of tandem axles is thirty-six ft. or more.

...ce in feet between the ...mes of any group of 2 ...re consecutive axles	Maximum load in pounds carried on any group of 2 or more consecutive axles							
	2 axles	3 axles	4 axles	5 axles	6 axles	7 axles	8 axles	9 axles
	34,000							
	34,000							
	34,000							
	34,000							
	34,000	42,000						
	39,000	42,500						
	40,000	43,500						
	S	44,000						
	E	45,000	50,000					
	E	45,500	50,500					
		46,500	51,500					
	N	47,000	52,000					
	O	48,000	52,500	52,500				
	T	48,500	53,500	53,500				
	E	49,500	54,000	54,000				
		50,000	54,500	54,500				
	B	51,000	55,500	55,500				
	E	51,500	56,000	56,000				
	L	52,500	56,500	56,500				
	O	53,000	57,500	57,500				
	W	54,000	58,000	58,000				
		54,500	58,500	58,500				
		55,500	59,500	59,500				
		56,000	60,000	60,000				
		57,000	60,500	61,000	61,000			
		57,500	61,500	62,000	62,000			
		58,500	62,000	63,000	63,000			
		59,000	62,500	64,000	64,500			
		60,000	83,500	65,000	85,000			
			84,000	66,000	66,000			
			84,500	67,000	67,000			
			65,500	68,000	68,000			
			66,000	69,500	69,500			
			66,500	70,500	70,500			
			67,500	72,000	72,000			
			68,000	72,500	72,500			
			68,500	73,000	73,000			
			69,500	73,500	73,500			
			70,000	74,000	74,000			
			70,500	75,000	75,000			
			71,500	75,500	75,500			
			72,000	76,000	76,000			
			72,500	76,500	80,000	80,000		
			73,500	77,000	81,000	81,000		
			74,000	78,000	82,000	82,000		
			74,500	78,500	83,000	83,000		
			75,500	79,000	84,000	84,000		
			76,000	80,000	84,500	85,000		
			76,500	80,500	85,000	86,000		
			77,500	81,000	86,000	87,000		
			78,000	81,500	88,500	88 000	91 000	91 000
			78,500	82,500	87,000	89,000	92 000	92 000
			79,500	83,000	87,500	90,000	93.000	93 000
			80,000	83,500	88,000	91,000	94.000	94 000
				84,000	89,000	92,000	95,000	95 000
				85,000	89,500	93,500	96 000	96 000
				85,500	90,000	95,000	97,000	97 000
				88,000	90,500	95,500	98,000	98 000
				87,000	91,000	96,000	99,000	99 000
				87,500	92,000	97,000	100,000	100 000
				88,000	92,500	97,500	101,000	101 000
				88,500	93,000	98,000	102,000	102 000
				89,500	93,500	98,500	103,000	103 000
				90,000	94,000	99,000	104,000	104 000
				90,500	95,000	99,500	105,000	105.000
				91,000	95,500	100,000	105.500	105.500
				92,000	96,000	101,000	105.500	105 500

The Gross Weight of vehicle and load shall not exceed 500 lbs per inch width of tire

The Overall Width of vehicle and load shall not exceed 8 feet 6 inches

The Overall Height of vehicle and load shall not exceed 14 feet

The Overall Length of any single vehicle shall not exceed 40 feet with or without load
Single Trailer Length 48 feet
Double Trailer Length 60 feet
Truck & Trailer Length 75 feet

...OTE It is unlawful to operate upon the public highways any single unit vehicle ...upported upon 3-axles or more with a gross weight including load in excess of ...0,000 lbs or any combination of vehicles having a gross weight in excess of 80,000 ...s without first obtaining an additional tonnage permit as provided for in RCW ...6 44.095 PROVIDED, That when a combination of vehicles has purchased license ...onnage in excess of 72,000 lbs. as provided by RCW 46.16 070, such excess ...cense tonnage may be applied to the power unit subject to limitations of RCW ...6 44 042 and this table when such vehicle is operated without a trailer

WHEN INCHES ARE INVOLVED Under six inches take lower Six inches or over take higher

The maximum load on any axle in any group of axles shall not exceed 1.2 times the load given in the above table divided by the number of axles in that ...p and shall not exceed the single axle or tandem axle allowance as set forth elsewhere For considering the number of axles in a group the front axle ... unit supplying motive power need not be included in the axle group

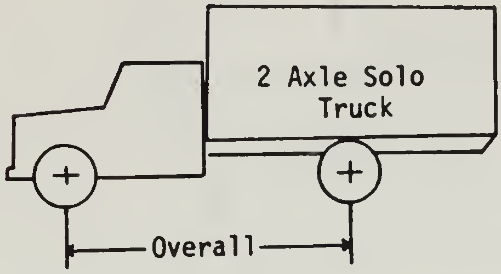
The maximum axle and gross weights specified in this table are subject to the braking requirements set up for the service brakes upon any motor ...cles as provided by law

It is unlawful to operate any vehicle upon the public highways equipped with two axles spaced less than seven feet apart, unless the two axles are so ...structed and mounted in such a manner as to provide oscillation between the two axles and that either one of the two axles will not at any one time ...y more than the maximum gross weight allowed for one axle specified in this table.

FORM 560-044 (Rev 5 85)   OX A-131

EXAMPLES OF OVERALL AND INTERNAL MEASUREMENTS TO DETERMINE GROSS WEIGHTS

1.



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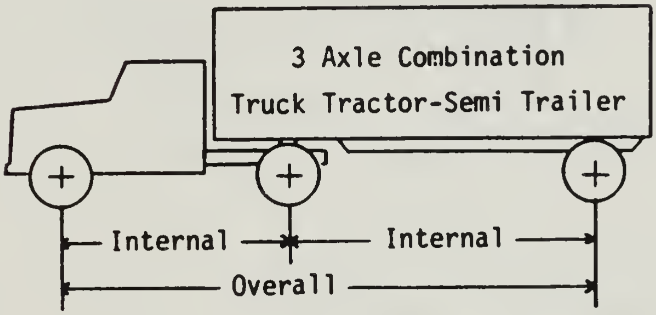

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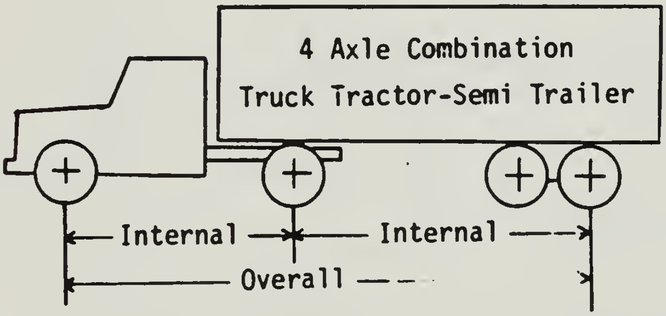

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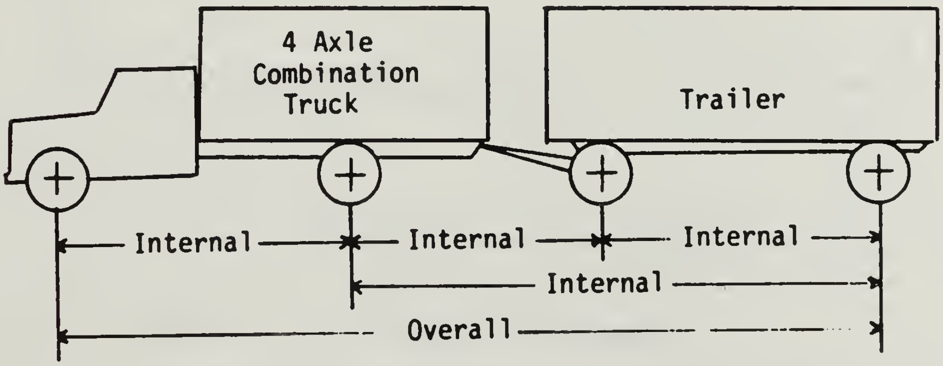

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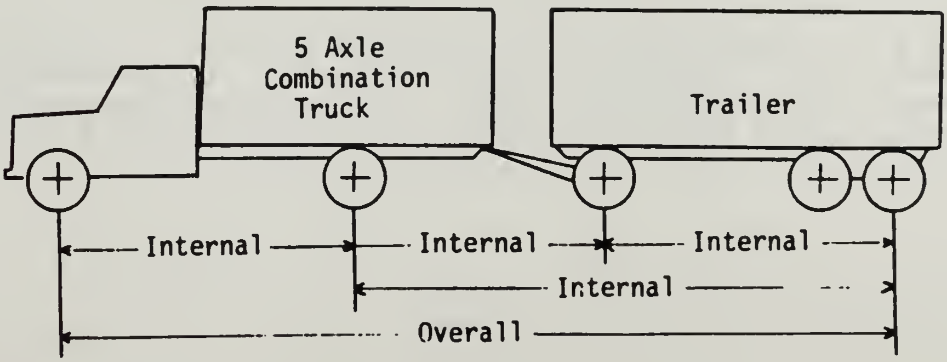

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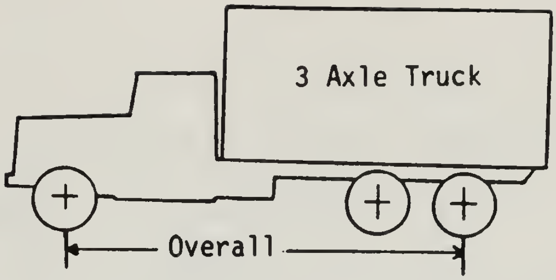

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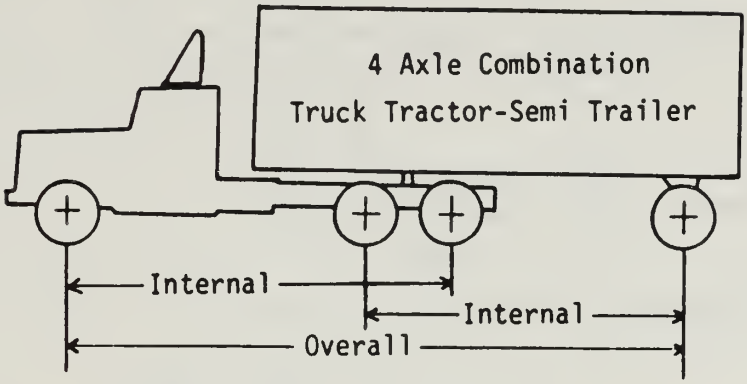

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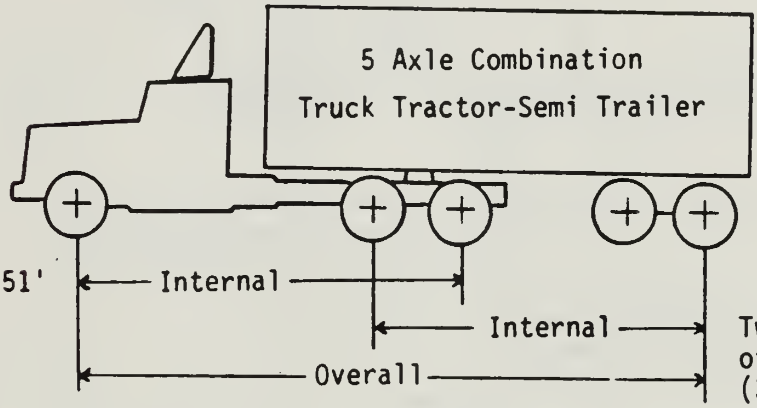
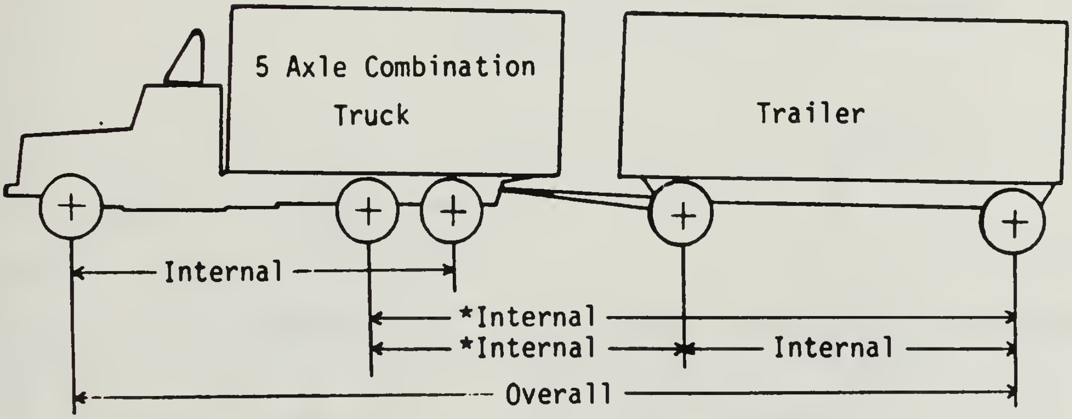


erall wheelbase of 51'
lows 80,000 lbs
termined by tire
ze steering axle

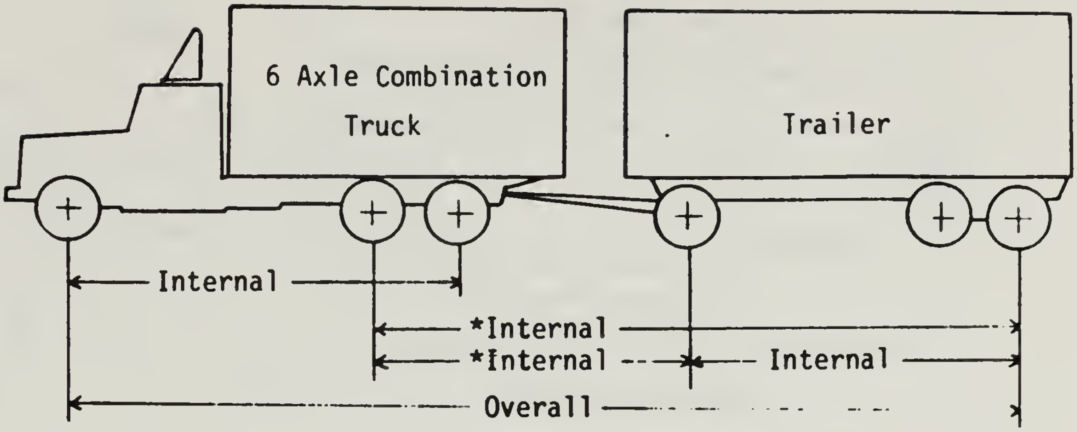
Two consecutive groups
of tandem axles
(36' allows 68,000 lbs)



* Indicates the critical measurements

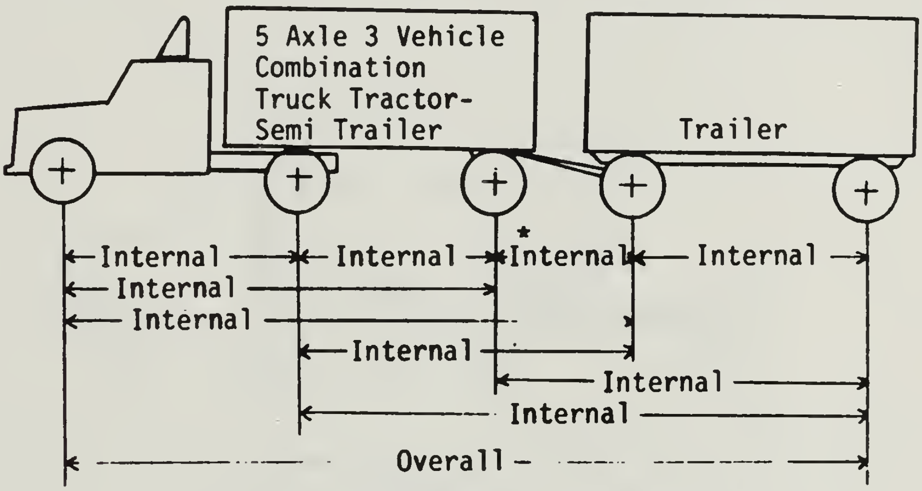
ample: 24' wheelbase from axle 2 to 4 allows by table (3 axle column) 54,000 lbs.
' wheelbase from axle 4 to 5 allows 40,000 lbs. These two examples for gross weight
rposes would be determined by the internal wheelbase from axle 2 to 5. Take the
tal wheelbase measurement from axle 2 to 5. This would by the critical measurement
34' from axle 2 to 5 applied to the 4 axle column would allow a gross weight of
,500 lbs.

10.

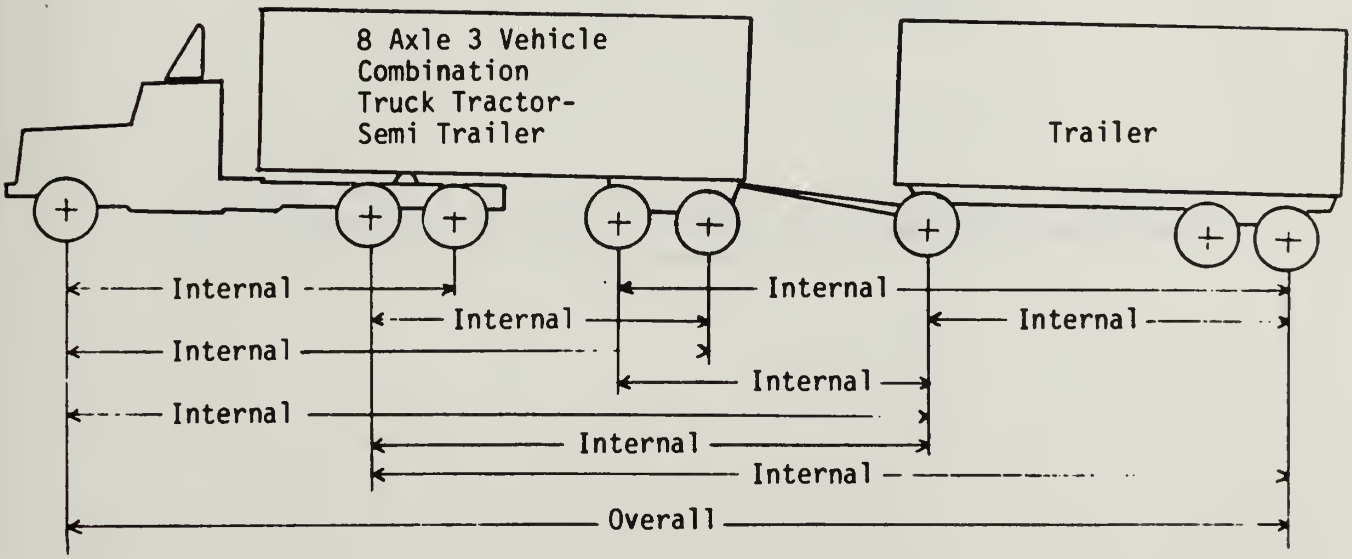


* Indicates the critical measurements

11.



* Indicates the critical measurement



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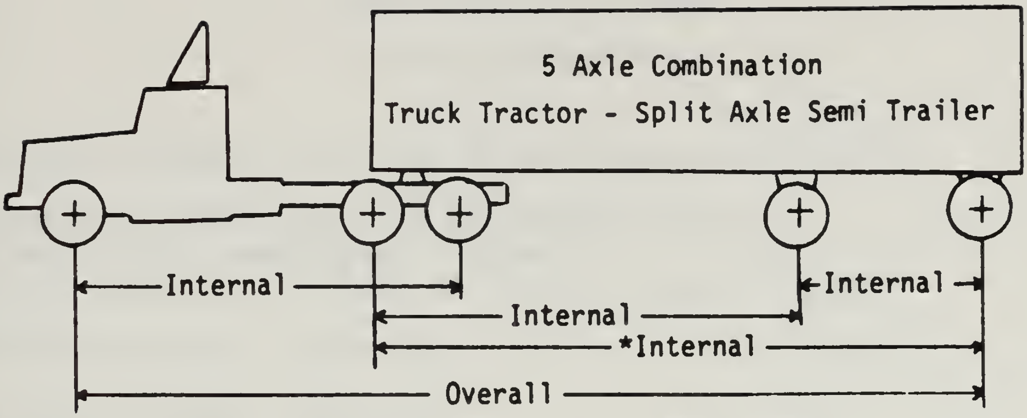

* Indicates the critical measurement

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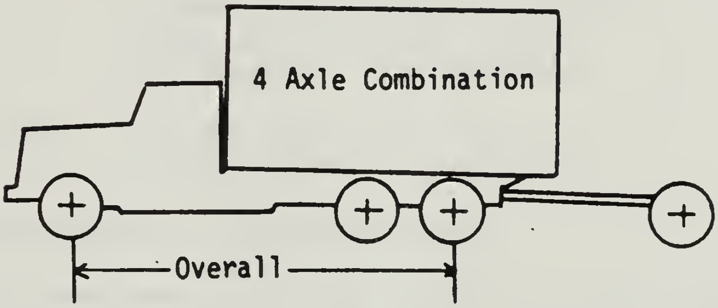

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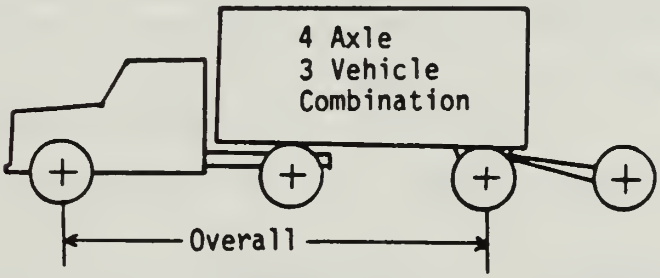


Vehicles towing a dolly axle not designed to support an appreciable part of the load will not be included in the wheelbase measurement for gross combination weight purposes.

WASHINGTON STATE PATROL

Trailer Requirements

MAXIMUM LENGTH ALLOWED -- 48 feet; 56 feet with Special Permit

MAXIMUM OVERALL LENGTH OF TRAILER AND TOWING VEHICLE --
Truck and trailer combination -- 75 feet
Two trailing units -- 60 feet; 68 feet with Special Permit

MAXIMUM WIDTH ALLOWED -- 102 inches

MAXIMUM HEIGHT ALLOWED -- 14 feet

If the length, width, and/or height exceed the maximum limits, applications for permits to move such vehicles should be addressed to:

Department of Transportation
Permit Section
Highway Administration Building
Olympia, Washington 98504
Telephone: (206) 753-6030

MAXIMUM WEIGHT ALLOWED -- 20,000 pounds on one axle
34,000 pounds on tandem axles

TIRE FACTOR -- 600 pounds per inch width of tire.

Axles spaced less than seven feet apart must provide oscillation between the two axles and that either one of the two axles will not at any one time carry more than the maximum gross weight allowed for one axle.

The combined weights for axles spaced three feet six inches and less shall not exceed the weights allowed for a single axle.

TRAILER HITCHES -- LIGHT SERVICE DEVICES - BREAKING STRENGTH FOR COUPLINGS AND BALLS

Trailer Classification	Trailer Couplings Designation	Minimum Ball Diameter-Inches (where ball-type hitch is used)	Minimum Breaking Point Requirements	Pounds
Class 1 (2,000 lbs. or less *MGTW)	No. 1	1 7/8	Longitudinal tension:	6,000
			Longitudinal compression:	6,000
			Transverse thrust:	2,000
			Vertical tension:	2,500
			Vertical compression:	2,500

*MGTW - Maximum Gross Trailer Weight

TRAILER HITCHES -- LIGHT SERVICE DEVICES - BREAKING STRENGTH FOR COUPLINGS AND BALLS (continued)

Trailer Classification	Trailer Couplings Designation	Minimum Ball Diameter-Inches (where ball-type hitch is used)	Minimum Breaking Point Requirements	Pounds
Class 2 (2,001 through 3,500 lbs. MGTW)	No. 2	2	Longitudinal tension:	10,500
			Longitudinal compression:	10,500
			Transverse thrust:	3,000
			Vertical tension:	4,500
			Vertical compression:	4,500
Class 3 (3,501 through 5,000 lbs. MGTW)	No. 3	2	Longitudinal tension:	15,000
			Longitudinal compression:	15,000
			Transverse thrust:	4,000
			Vertical tension:	7,000
			Vertical compression:	7,000
Class 4 (5,001 through 10,000 lbs. MGTW)	No. 4	Ball & bolt shall be of such size and strength as to conform to the minimum breaking strength requirements of the mating coupling required for the specific load of Class 4 trailer	Longitudinal tension:	MGTW x 3
			Longitudinal compression:	MGTW x 3
			Transverse thrust:	MGTW x 1
			Vertical tension:	MGTW x 1.3
			Vertical compression:	MGTW x 1.4

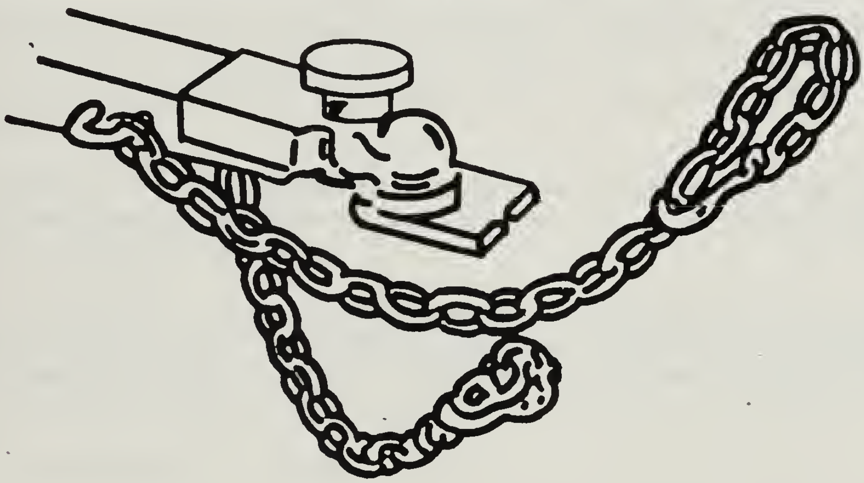
SAFETY CHAINS AND ATTACHING MEANS REQUIRED -- (1) Strength Requirements. Each safety chain and each attaching means shall meet strength requirements as shown in WAC 204-70-99004, Tables 3 and 4, and defined in WAC 204-70-040.

(2) Installation and Connections. The means of attachment of safety chains shall be located equally distant from and on opposite sides of the longitudinal centerline of the towing vehicle and of the trailer. Each means of attachment shall not be common with or utilize fasteners common with a ball or coupling. No welding operation shall be performed on a safety chain subsequent to this manufacture, including the method of attachment to the towed and towing vehicles. Safety chains shall be so connected that the slack for each length of chain between trailer and towing vehicle is the same and is not more than necessary to permit the proper turning of the vehicles. When passing forward to the towing vehicle, safety chains must be crossed in such a manner as to prevent the tongue from dropping to the ground and to maintain connection in the event of failure of the primary connecting system.

LIGHT SERVICE DEVICES - MINIMUM STRENGTHS OF SAFETY CHAINS AND ATTACHING MEANS*

Trailer Classification	Minimum Longitudinal Load, Tension, Pounds (see WAC 204-70-99005, Figure 3) Each Safety Chain	Each of Two Chain Attaching Means
Class 1	2,000	2,000
Class 2	3,500	3,500
Class 3	5,000	5,000
Class 4**	MGTW	MGTW

Typical Double Safety Chain Installation:



BRAKES -- Every trailer having a gross weight exceeding 3,000 pounds must be equipped with brakes on all wheels and capable of being applied from the towing vehicle. Any trailer whose gross weight is over 3,000 pounds must be equipped with a device which will automatically apply the brakes in case of a breakaway.

Trailers with a gross weight of 3,000 pounds or less must be equipped with brakes if the weight of the trailer(s) exceeds 40 percent of the weight of the towing vehicle. Trailers manufactured and assembled prior to July 1, 1965, having a gross weight less than 2,000 pounds need not be equipped with brakes.

LIGHTS -- Two red tail lamps, one located near each side on the rear of the trailer. Two stop lamps at the rear which may be in conjunction with the tail lamp units. The license plate shall be illuminated by a white lamp which may be in conjunction with either tail lamp. Two red reflectors, one located near each side on the rear of the trailer. On trailers over 80 inches in width, two red clearance lamps on the rear located at the highest and widest points of the permanent structure, two amber clearance lamps on the front located at the highest and widest points of the permanent structure, and three red identification lamps on the rear located near the top of the permanent structure of the trailer as close as practical to the vertical centerline. On trailers 30 feet or more in overall length, on each side, one amber side marker lamp and one amber reflector, centrally located with respect to the length of the trailer.

SPLASH GUARDS -- (fenders or flaps) a device to effectively reduce wheel spray, extending to the center of the axle and as wide as the tire behind which they are mounted.

TURN SIGNALS -- Electrical turn signals operated from the towing vehicle are required.

SERIAL NUMBER -- Required for registration in state. May be stamped by the manufacturer onto a conspicuous permanent part upon the outside of the trailer, or placed on a manufacturer tag where it may be easily inspected.

LICENSE PLATE -- Required on all trailers regardless of size.

CERTIFICATE OF REGISTRATION -- Issued to trailers registered in Washington.

CERTIFICATE OF TITLE -- Issued to trailers registered in Washington.

PARKING OFF HIGHWAY FOR AN OVERNIGHT STAY -- Not permissible on interstate freeways.

TOWING VEHICLE -- It is permissible to use a commercial type vehicle to tow a trailer coach. The towing vehicle must be able to maintain a speed which will not impede traffic.

TIMES OF OPERATION -- It is permissible to tow a legal size trailer at all times in this state, including Saturdays, Sundays, and holidays. Overlegal size trailers will be restricted to the times and highways indicated on the overlegal permit.

RIDING IN TRAILERS -- Illegal.

FUEL RESTRICTIONS -- Gasoline stoves: None. Butane tanks: None.

STATE REGULATIONS IN REGARD TO SANITARY EQUIPMENT -- None.

MOBILE HOMES PARKED IN TRAILER PARKS OR COURTS AND NOT USED ON HIGHWAYS -- Required to be registered for the current year.

MOTOR HOMES -- Requirements same as trailer coaches.

GENERAL SPEED -- Every person operating any vehicle shall obey all posted speed limits and drive at a speed no greater than is reasonable and proper under conditions existing, weight of vehicle, and type of highway.

NONRESIDENT -- Licensing regulations will be governed by the reciprocity agreement in effect with the non-resident's home state. Visitors temporarily sojourning are allowed six months.

APPENDIX H

Excerpts of the Ostrander Report

The following are extracted from an unpublished report prepared by Mr. Greg Kreshel, Vice President of Engineering for Alloy Trailers, Inc. (Spokane, WA) and are reproduced with his permission.

The report documents the field error which exists when attempting to weigh Class 8 tractor semitrailer combinations axle-by-axle. Operators, working closely with the weigh master at the scale site, weighed each combination several times in a variety of ways. The weight was recorded as the truck was driven onto the scale, axle by axle, and compared to weights of the axle group as a whole. Additionally, weights were recorded as the combinations were driven <u>off</u> the scale platform, again axle by axle, and the readings compared.

As is evident, differences existed between the results. The implications of this study for scale accuracy are obvious.

Report on Scale Weighing
at
Washington State Patrol "Ostrander" Scale on I5 South
on
May 25, 1988

This was done to determine effectiveness of weighing individual axles of multi-axle combinations typically interconnected with standard springs & equalizers.

By weighing individuals, or combinations of axles with other axles off the 10 ft. scale platform the weights wouldn't match, add up to totals, or by using mathematics, it appeared the axles were varying in weight.

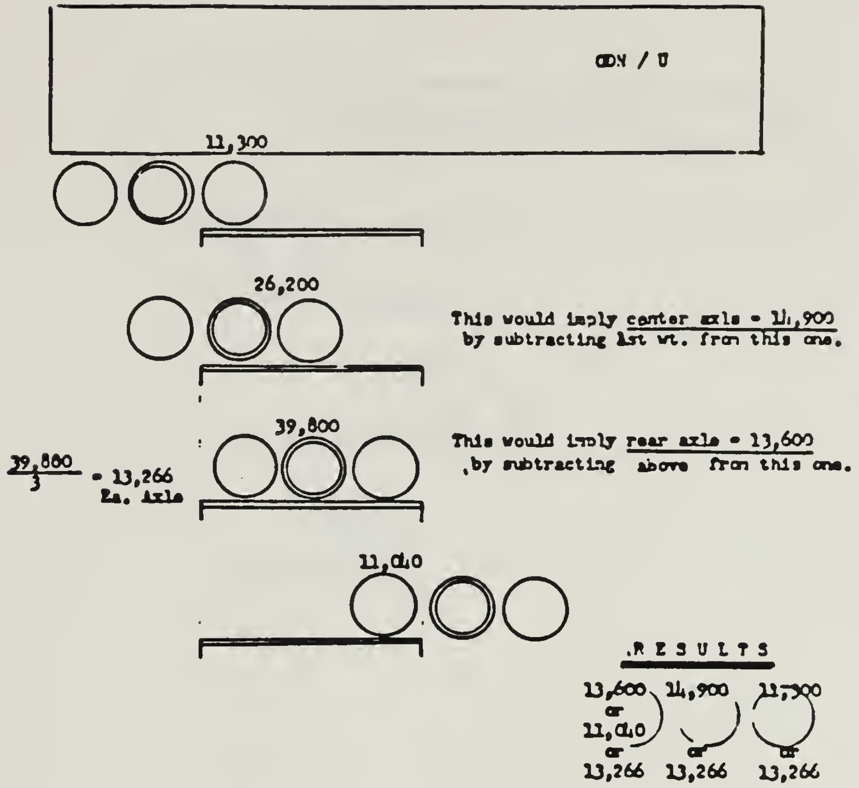
When parts of the integrally connected suspensions are pulled off the scale values recorded on the scale appear to be less than those calculated, averaged, or seen with individual portable scales under all wheels, or "entire unit" scale weights.

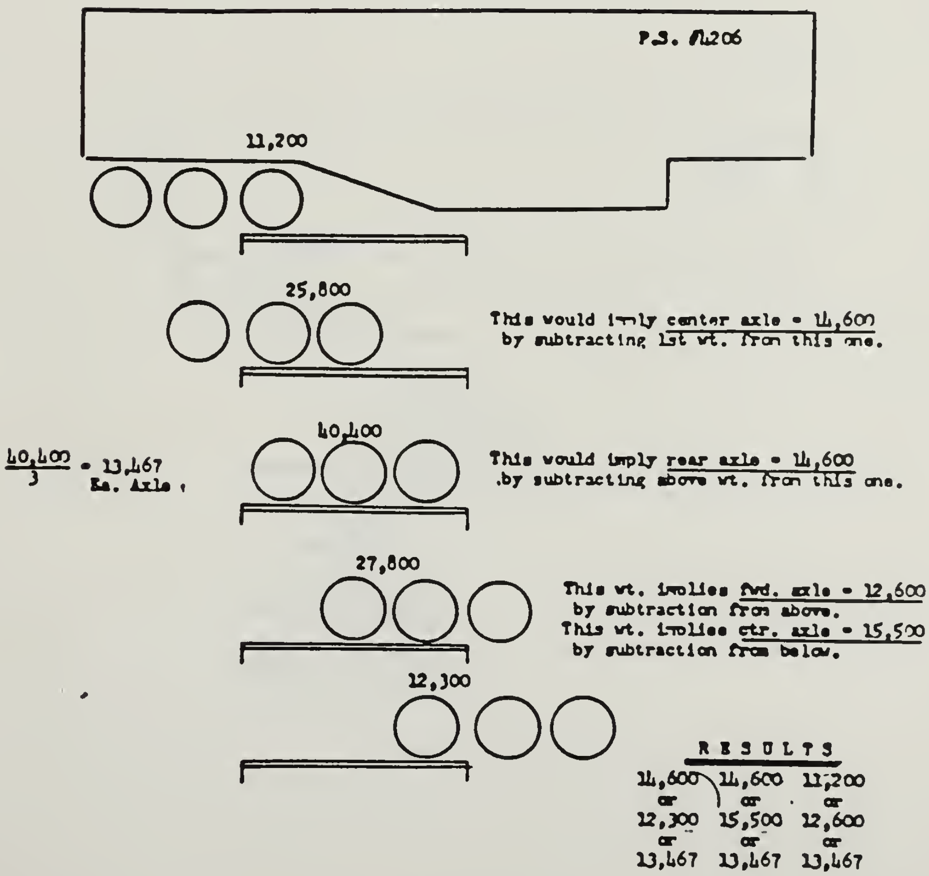
Therefore, it appears that the use of platform scales:

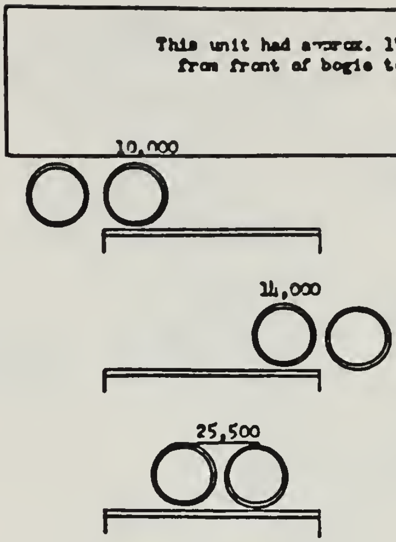
Level with surrounding approaches;
Calibrated carefully;
Diligently read;
Carefully loaded;

still does not provide accurate enough information to administer weight regulations for multi-axle combinations that are integrally connected.

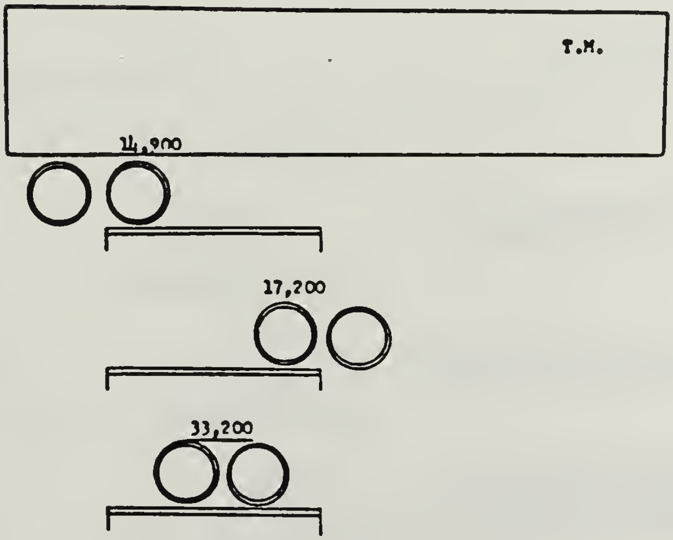
This data is in full agreement with previous experience and data reported in the attached FLEET OWNER report.


11,300
26,200
This would imply center axle = 14,900
by subtracting 1st wt. from this one.
39,800
This would imply rear axle = 13,600
by subtracting above from this one.
$\frac{39,800}{3}$ = 13,266
Ea. Axle
11,040
RESULTS
13,600 or 11,040 or 13,266
14,900 or 13,266
11,300 or 13,266

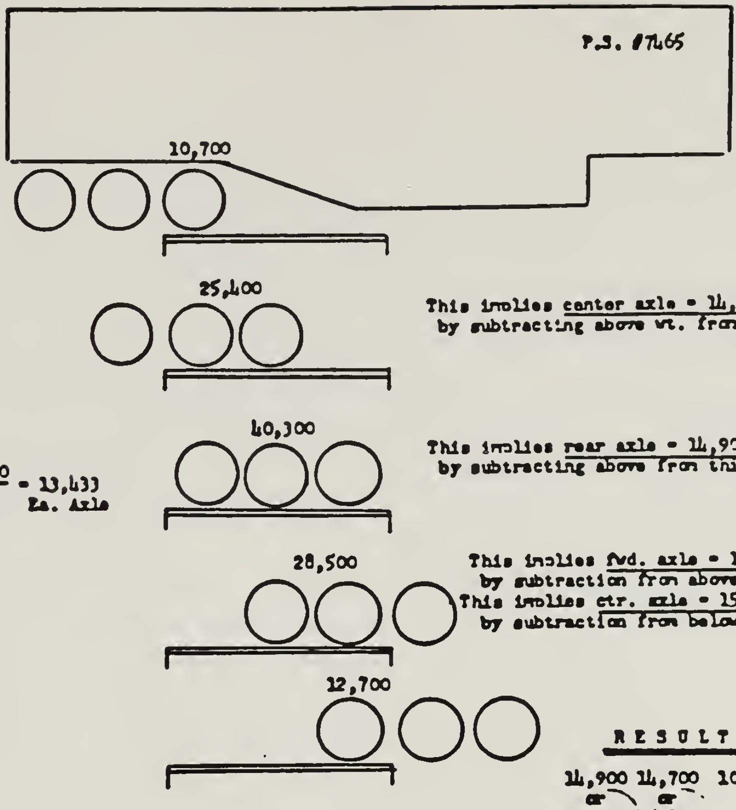

P.S. #4206
11,200
25,800
This would imply center axle = 14,600
by subtracting 1st wt. from this one.
40,400
This would imply rear axle = 14,600
by subtracting above wt. from this one.
$\frac{40,400}{3}$ = 13,467
Ea. Axle
27,800
This wt. implies fwd. axle = 12,600
by subtraction from above.
This wt. implies ctr. axle = 15,500
by subtraction from below.
12,300
RESULTS
14,600 or 12,300 or 13,467
14,600 or 15,500 or 13,467
11,200 or 12,600 or 13,467



Added wt. = 24,000



Added wt. = 32,100



This implies center axle = 14,700
by subtracting above wt. from this one

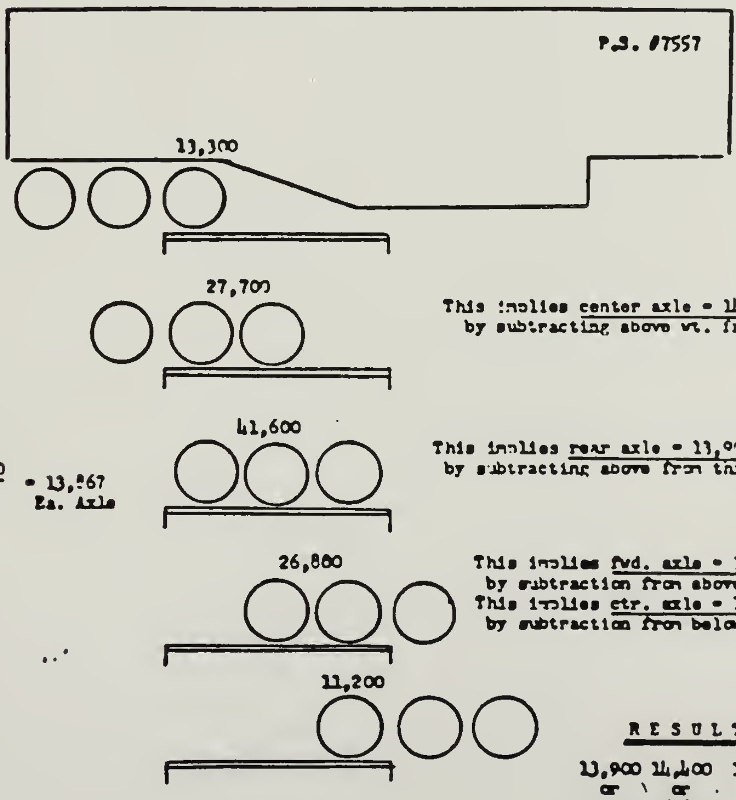
This implies rear axle = 14,900
by subtracting above from this one.

$\frac{40,300}{3}$ = 13,433
Ea. Axle

This implies fwd. axle = 11,800
by subtraction from above.
This implies ctr. axle = 15,800
by subtraction from below.

RESULTS

14,900	14,700	10,700
or	or	or
12,700	15,800	11,800
or	or	or
13,433	13,433	13,433



This implies center axle = 14,400
by subtracting above wt. from this.

This implies rear axle = 13,900
by subtracting above from this one.

$\frac{41,600}{3}$ = 13,867
Ea. Axle

This implies fwd. axle = 14,800
by subtraction from above.
This implies ctr. axle = 15,600
by subtraction from below.

RESULTS

13,900	14,400	13,300
or	or	or
11,200	15,600	14,800
or	or	or
13,867	13,867	13,867

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